Department of Mechanical and Aerospace Engineering

Analysis of high resolution indoor environment data to identify the occupancy profiles using statistical approach

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Abstract

Increasing of energy consumption is a challenge to the commercial buildings. ‘Building and Energy Management Systems’ is a major task for commercial sector and slowly became a trend. This is due to the lack of scalability in occupancy counting technologies which tends to be the base for all challenges. Since occupants’ behaviour have a direct impact on the buildings performance, the tracking of occupancy level based on their behaviour is set to be the main plot of this research. This paper works in developing a predictive occupancy models for the commercial buildings based on the statistical approach.

The statistical approaches like Correlation and multiple regression analysis are tools that have been proven to aid with indoor environment parameter calculations to track and set the occupancy level predictive model for the commercial buildings. The indoor environment data’s (Temperature, Relative Humidity, Lighting Audio, and Motion,) involved in this calculation are obtained from the ‘Be-spoke’ multifunctional sensors. Others vary with time (e.g. Weather and occupancy) and the analysis identified the accurate regression equation in order to create a unified occupancy predictive model.

The seasonal approach coupled with whole plan data gave a 75% of accuracy in prediction. The research concludes by providing a regression equation with the recommend and selective dominant factors for the future studies which is due to its unpredictable and random nature. As a suggestion it is advised to follow upon previous studies that have been carried out it. It’s also beneficial to include additional parameters such as CO_2 level that have major impact on occupancy level and integrating a new analysis approach named ‘Regularised Linear Regression Analysis’ would help in tuning the result with better accuracy.

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First and foremost, thanks to almighty Allah, for guiding me in the right way.

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Finally I would like to dedicate this work to my parents and friends.

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Nomenclature

1) POE- post occupancy evaluation
2) BAS- Building automation systems
3) BEMS- Building energy management systems
4) IT- Information Technology
5) EUI- Energy Use Intensity
6) ECI- Environmental Condition Indicator
7) IEQ- Indoor Environmental Quality
8) OS- Occupancy Sensor
9) CS- Control Systems
10) PIR- Infrared or Passive Infrared
11) US- Ultrasonic or Ultra Sound
12) DT- Dual Technology
13) ESRU-Energy System Research Unit
14) Temp- Temperature
15) RH- Relative Humidity
16) LUX- Lighting
17) DB- Audio
18) PIR- Motion
19) MAR- Multiple Regression Analysis
20) CA- Correlation Analysis
21) Occ. - Occupants

1. Introduction

The global contribution on energy consumption is mainly from the buildings (commercial and residential buildings) where people spend half of their life. Both the developed and developing countries struggle to control their energy consumption (Anna Carolina Menezes, 2012). However the developed countries have indulged in research involving building engineering informatics which has a detailed vision towards bringing out a sustainable environment within the area of approach (Courtney, 1976). The significance of the research lies in the area of connecting building features (Hancock, 1992), designs and operation in line with the people's comfort zone and also with the sole aim of having projection in side of energy management, controlling and intelligent energy saving systems (Marvin, 1994).

According to the recent legislative policies (Jason Palmer, 2011) and from the total effect of UK's commercial sectors energy consumption drove me towards this research project. To bring some dynamic changes within an indoor environment together with reducing the energy consumptions an idea is laid to measure the occupancy level within an indoor environment which would then be helpful to improve the energy performance of the built environment as well as reducing the cost (IEA, 2012). Moreover to bring about this improvement the key factor lies in identifying the energy demand within the indoor environment which further depends on multiple factors like residential sector, appliances and intense activities like behaviour of the residents and their impacts (Andersen, 2009).

The major energy consumption of the buildings can be significantly controlled by monitoring and analysing the level of occupants within the indoor environment and such actions will lead to numerating the headcounts over the period of occupancy stay and monitoring them via advanced sensor technology (Kofmehl, 2012). This sensor technology has been used for calculating the data which would further be useful for measuring the headcounts in order to show some significant savings in the total energy consumption (Shuai Li, 2012).

The aim of this research is to provide an intense study on building energy management systems (LAUSTSEN, 2008), how the real time monitoring systems in the buildings are deployed and their functions/ purposes in terms of frequency (Peter T. Szemes, 2011), position, and high resolution data handling (Pert, 2013). The primary idea is to bring up some striking changes in high level data analysis through a systematic approach i.e. to have efficacious monitoring systems with well-equipped clusters of sensors to measure and monitor the data and then to narrow down into data analysis with an effective statistical approach.

Moving on, the research will now focus on topics such as world energy look, BEMS, Occupancy profiles, BAS, applications of BEMS, targets and legislative policies, background problem, impacts of occupants on BEMS, energy conservation, relationship between climate and the buildings, types of occupancy sensors and it's technologies smart buildings and people.

1.1 Purpose of this research

Monitoring the multiple parameters within an indoor environment in order to find the number of occupants in particular test location by dividing building plans (Floor) into multiple zones (Anna Carolina Menezes, 2012). The aim of this research work is to find an exact patent to identify and define the occupancy profile. There may be various outcomes from this study of approach but the key aim is to control the energy consumption within an indoor environment, which is achieved by interfacing acquired occupancy profile within the control algorithm and this is derived based on the routines and occupancy patterns within that particular area.

When moving to the accuracy of the systematic approach, it widely varies from systems to systems. Which is affected by different factors either with the hardware systems or due to the missing data. The sensor systems often found to be unreliable due to effects of environmental interference and factors like their operating principles (Hancock, 1992).

The aim of identifying and evaluating the Post occupancy level finds its applications in many fields including like building design. This paper uses the POE technique to compare and analyse with the indoor environment data which has been monitored and collected through the sensor based data acquisition system. In order to set the exact occupancy profile within that indoor environment the data has been approximated, interpolated and regressed using the multiple regression analysis-statistical approach.

The core aim of this thesis is to come up with the humble work results that would make some important contribution in the field of BEMS. In which the main concentration is based on how to set the occupancy profile with the help of statistical approach called "Multiple Regression Analysis". Since occupants' behaviour have a direct impact on the buildings performance, the tracking of occupancy level based on their activities is set to be the main plot of this research. Further, this paper will analyse the indoor environment parameters in relation to the level of occupancy over the weekdays. As explained above, a multiple regression analysis was carried out to develop an equation (Predictive occupancy model) which allow the accurate tracking of future occupancy patterns. With this developed predictive occupancy model it is possible to control the heating, ventilation and air-conditioning systems, which in turn achieves efficiency and thereby reducing the energy costs.

2 Literature review

2.1 Introduction

The chapter will scrutinize the relevant past and present studies that have been carried on World energy outlook, BEMS for commercial buildings, Occupancy sensors technologies and types, and BAS. The chapter initially starts with the general description on world energy outlook and how it affects the UK. Then I discussed about how to bring the energy efficiency in the commercial building sectors. Then the future researches to bring the sustainability in the commercial building sectors. Further it discusses about the techniques like BEMS, their application and impacts in the commercial building sectors, and occupants pattern and its behaviour concepts, in detail. The chapter finally concludes with overview of the similar studies undertaken around the world.

2.2 World energy outlook

From the housing energy fact files and the data's from the desks of policy makers, researchers and public participants (IEA, 2012), the amount of energy used in commercial and residential buildings is halfway more than quarter (Courtney, 1976). The over consumption leads to CO_2 emission which in turn dominates the other major sectors like transport and industries (Jason Palmer, 2011)

According to the policies and from the context of legislation the use of UK's energy should obtain 15% from the source of renewables by 2020 which is the minimum requirement set by the EU renewable energy directive. It's impossible to meet the 2050 targets (Jason Palmer, 2011), without making any considerable changes in the plot of greenhouse gas emissions from houses (ECUK, 2013). In order to bring some effective changes from the commercial/ business sector the government had already promoted

DECC's business plan for 2011-2015, which is aimed to reduce wasted energy, thereby increasing efficiency by new renewable technologies (Dr Jim Watson, 2012).

In order to act smart and to think about the foundations of global energy systems, the global energy market should be focused and keenly studied. It's also important to have some basic knowledge on growth and energy use in the commercial buildings which would benefit the future generation and arise awareness on energy consumption.

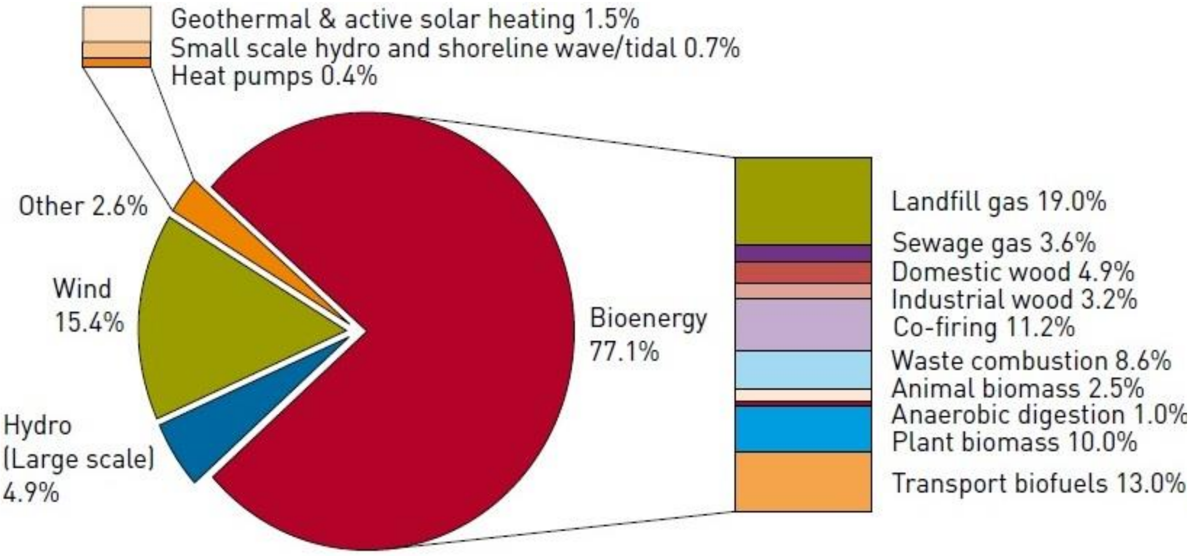

Figure 1- Renewable Energy Shares in UK (ECUK, 2013)

To meet the 2050 targets set by the government the commercial building should set the objectives to cut down the greenhouse gases and have to bring some efficient methodology in terms of energy usage (IEA, 2012). The government has already started taking initiatives on this issue to bring awareness on the use of electricity. As a result of this, and from the recommendations received from the expert/ researchers and policy makers the government started implementing the smart meters which would educate and help the people to know more about their energy usage (Dr Jim Watson, 2012).

Creating global energy data framework would bring better understanding about the nation's energy usage and their impact on the energy efficiency (ECUK, 2013). This would be the biggest contribution to the energy sector which will have many interlinked gains (Jason Palmer, 2011). Since the global energy consumption has been doubled the in the last two decades it's important to think more efficiently. The proper utilization of the energy resources would stop the increase in energy demand, which further results in improved energy efficiency (Jason Palmer, 2011). Due to the technical and scientific advantages in the field of BEMS, has ensued the development of research in identifying the occupancy profiles within an indoor environment (Haris Doukas, 2007).

2.3 Research to create future sustainable built environment

This study identifies many global sustainability challenges and suggestion to overcome that. Aim of this study is to understand the need of this research and to know about the global environment impact, solution for today's problem and challenges for the future. I strongly believe in topics that are to be discussed below which gave a clear idea about this project and it's been a great stem to do this research.

2.3.1 Building Energy Management Systems

The main aim of BEMS is to provide the architecture/ pattern of discipline that saves the building operating cost by improving the efficiency of the building's energy systems (Jessica Granderson, 2009). The efficiency is improved by controlling the energy usage of the building and this is being done without polluting the normal activities of the building such as energy usage and the occupants comfort (Hancock, 1992).

The functions of BEMS are classified in to three types and they are monitoring. Controlling and optimising (B. Raphael, 2007). This installation of the BEMS minimises the wasted energy which successively saves the money and reduces the carbon emissions. To manage and to control the energy used within particular built environment they need to monitor, investigate, and analyse several parameters which depends on their functions and area of optimisations (Ammar Ahmed, 2010). The BEMS often manage the level of lightning, heating, air conditioning and ventilation in relation with level of occupancy within that particular built environment.

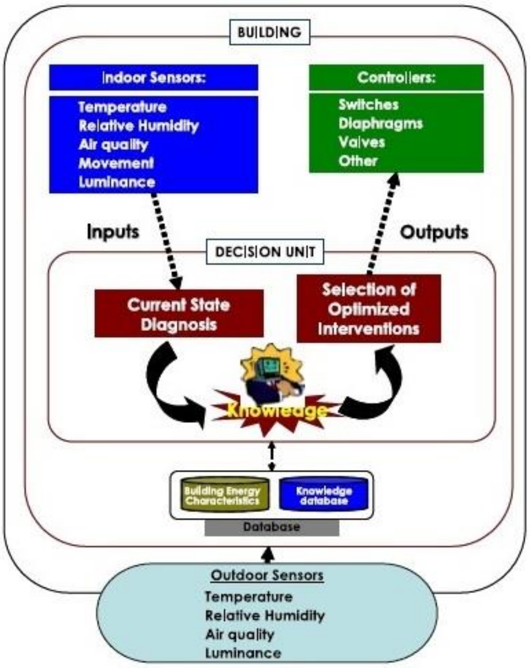

Figure 2- BEMS- Model (Pieter de Wilde, 2012)

The BEMS has become essential for all types of commercial buildings more than desirable, it's became unavoidable solutions for all types/sizes of businesses due to many reasons like demand of electricity, persistence rise of fuel cost, and carbon footprints (Haris Doukas, 2007).

The components of the BEMS systems are classified into six types. They are sensors, actuators, field panels, MODEM's, communication links and controllers. Their configuration and operation will be deeply discussed below in the technical topics (Pieter de Wilde, 2012).

2.4 Application of BEMS in Commercial Buildings

Since my thesis concentration and test location is purely based on commercial buildings, to support my background research I'd like to come-up with the some evidences. Almost 40% of the commercial buildings annual cost is spent on electricity (Courtney, 1976).

The BEMS is installed with an aim to control the energy consumption and the potential of the systems is assessed based on the functions and the terminologies used for the controlling (Smith, 2007). The implementation of the BEMS within the commercial building is achieved to save money which would be spent on the energy and issues related with the buildings energy cost. Initially the level of savings depends on the operating hours of the particular site location which is totally depends on the level of occupants and this is addressed as the significant factor of this project (Tianzhen Hong, 2013).

The areas like offices where the occupants and their actions play a major role in bringing changes in their energy usage pattern. For an instance one of the poorly executed aim is switching off the lights when leaving the work place but that has a dramatic impact in the offices energy bills. Which is not only on the lights even extends up to computers, heating & air conditioner and office equipment's like printers, monitors and photocopiers.

Other than controlling the energy consumption the most important factor of the BEMS is to improve the efficiency that would help in reducing the operating costs other than man powers.

2.4.1 Impact of occupants on BEMS

The behaviour of the occupant has a twofold effect within the office and they are direct and indirect effects. The usage of occupancy level and occupant behaviour during the design helps in achieving the high efficiency building/ low energy building with low carbon emission. The occupancy behaviour is believed to be the driving factor in this field of research. The behavioural studies proves that 5 to 30% of energy savings can be made (Andersen, 2009).

Due to the change in number of people within the particular built environment where the BEMS is installed experiences multiple effects that alters the requirement of heating and air-conditioning. The human effects includes the amount of heat and CO_2 they emit which further depends on the individual's, their weight and the level of activity they perform (Jessica Granderson, 2009).

The movement of the occupant over the breaks, meetings or leisure time in an office environment will have a considerable effects on the energy usage. From the aggregated factsheet it is clear that the average heat produced in a room with the count of nine people will be more than 1kW per hour (Jason Palmer, 2011). This proves the significance of having BMES.

2.5 Occupant behaviour

The comparison study between the occupation behaviour and the offices indoor environment data aims to give a significant factor that has a further impact on energy usage of the offices (Andersen, 2009). The occupancy behaviour study is used to assess the types of discrepancies and how that would have ultra-effects on the energy usage. Comparing the occupant behaviour in terms of their presence, mobility, and in numbers with the available indoor environment parameters like temperature, lighting, heating, audio, visual and the humidity will bring a dramatic change in offices energy usage pattern (Anna Carolina Menezes, 2012).

Studies and researches on identifying occupancy patterns should be encouraged because they have significant impact on energy use of commercial buildings. The occupancy behaviour studies can be done on setting the occupancy number which will be assumed based on the test location and their functions in relevant with the occupants (Heng-Tao Wang, 2010). The effect of post occupancy survey add credits to the occupant behaviour studies and makes it more effective in terms of accuracy.

To increase the sensitivity and accuracy of the systems, the zone can be further divided into multiple zones (Pert, 2013). The significance of setting occupancy profile would rank and prove the effectiveness of the selected zone which thereby help in reducing the cost and usage of the energy. The third party data's like occupants shift from multiple zones, external effects like opening and closing of the windows and doors of the entry passages will play an important role in creating the profile because they have an impacts on indoor parameter.

In order to make a realistic prediction of occupancy profile there is a need of evaluating operational performance. The evaluation of operational performance consist of regular monitoring, writing feedback on their impact, ensuring the conscious use of the zones by the occupants, better control and management of the relevant parameters and the better communication.

2.6 Targets & legislative policy

Energy efficiency is the term which is set as the target and many policies have been recently reorganized to achieve them. Particularly the UK's commitment towards the productive setting of goals is tremendous. According to the scale and from the fact sheets, relevant findings the UK government directive has set the target to produce the clean energy through renewables by 2020 (Dr Jim Watson, 2012). Their investment in the field of R&D for renewables would indeed improve the contributions and will make the targets to come close by. In addition to 2020 target they have taken committed actions on emissions reduction. They aim to create the low-carbon economy also comes under the climate change act (IEA, 2012).

There is a robust action by the government that clearly ensures the 2020 target and meeting further growth through the renewables (ECUK, 2013). There are many pros and cons in reaching this 2020 target, which can be clearly seen by its start. The overall achievement in the years 2009 & 2007 was 4.8% (Collectively) and this was not up to the expected standard (Jason Palmer, 2011). Due to this poor starting position the government had planned to have shift program in renewable policy which brings more positive approaches than the previous one. Still they need to overcome certain issues such that widening the feed in tariff systems and to realise the total potential of the renewables.

Moving towards the issue of efficiency in commercial sector which is the globally met problem and are in line with the consumer welfare issues. The key aim of the G8 summit in 2008 was to set the clear definition for the energy efficiency. The IEA proposed 25 measures to achieve the efficiency, which on implementing could save the one-fifth of the global issues on efficiency by 2030 (IEA, 2012). Though the efficiency has improved but still EU have some plans on improving them further by implementing new strategies across all sectors.

2.7 Background to the problem

Globally and nationally, the commercial buildings holds an important place in energy consumption (Courtney, 1976), which contribute significant amount of energy wastage and this is taken as the background problem. The source and solution for the problem will be discussed below.

Taking the office buildings which must be improved to attain major gains in reducing the wastage of energy (Cheng, 2010). The occupancy behaviour plays a dominant role in assessing this problem, the behavioural study coupled with parameter analysis helps in bringing solution to this problem (Brian Pilkington, 2011). Scoping deep down to the background problem, the main problems are categorised in an order as, the performance of the energy systems, occupant behaviour within that particular office location, effect of vampire applications.

To solve this problem the commercial buildings should be employed with proper BEMS systems, in order to identify the requirement of the systems that would fit in with the office sectors, several factors should be analysed. The factors like occupant profiles, effect and impact of internal and external environment. The key issues is to improve the efficiency and that should be done by incorporating the technical strategies on consumption pattern (Ammar Ahmed, 2010).

Several studies concerning occupancy behaviour on commercial building should be analysed (Andersen, 2009), questions comparing the system potential with occupant behaviour should be raised, and sequential investigation on different technology should be made.

2.7.1 Efficient use of energy

The amount of energy employed and their drivers of efficiency is totally depends on the choice of energy usage and the energy saving technologies followed. Those technologies have a great impact on the energy costs faced by the buildings, emissions of greenhouse gasses and future availability of the energy sources (Courtney, 1976). In most of the studies the fact of energy efficiency is plays a secondary role instead the primary important is given to the source of energy, components/ systems, and the consumption.

The service demanded factors such as building size, real energy prices and population also have a great impact and they became one of the trends to design the energy efficiency policies with a clear focus. Moving to the final factor that would affect the buildings overall efficiency are building designs and climate change.

The efficient use of energy can be set into a goal by measuring energy performance of the building, the steps involved in assessing these performances, are involved in calculating energy use intensity and environmental condition indicator.

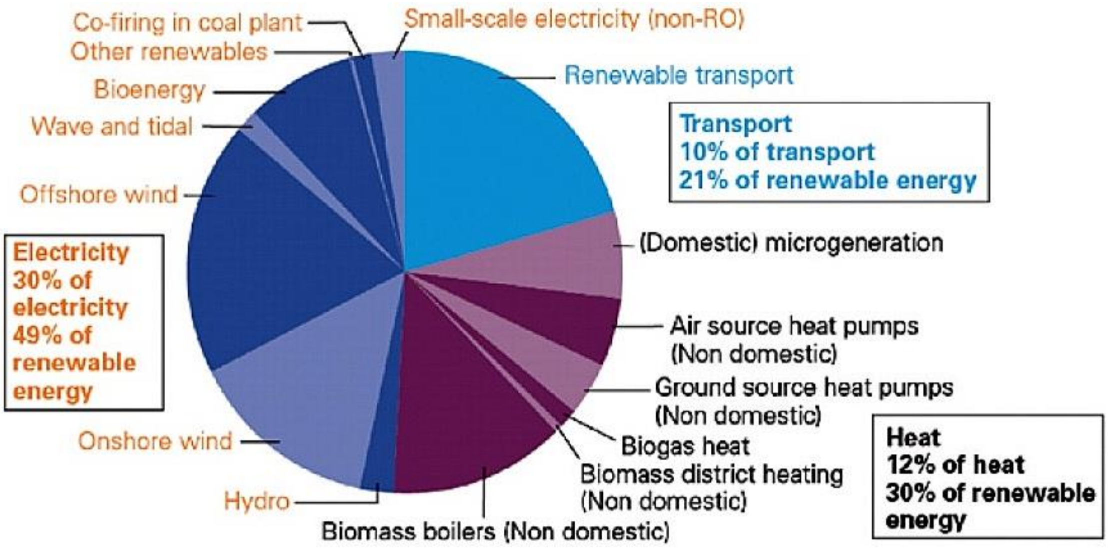

Figure 3-Understanding Energy Use and Systems Energy (Hancock, 1992)

The selection of energy efficiency measures should include the clear process overview with proper considerations such as operations, building envelope, controls, utility/ fuel supply and overall performances (Brian Pilkington, 2011).

2.7.2 Climate and buildings

As the climate of the world changes, the consumption, efficiency of energy varies with climate which is sensitive factor that is expected to change (Smith, 2007). It's too obvious in the commercial building sector that there will be a change in energy consumption and in way the energy is being used in the area of space conditioning. From many project it is experienced that the effects of climate change shows difference in the supply and demand and in energy prices too.

The overall change in climate such as temperature (both internally & externally), precipitation, sea level, and the severity of extreme cases will have adverse effect in the energy production and consumption. They further varies with seasonal approach, for an instance the increase in temperature will have a change in the consumption.

The climate have a relationship with the buildings that further influences the building energy consumption. The impacts is based on the type of climate change because the internal climate have a direct impact on the building energy systems (Hancock, 1992).

2.8 Occupancy sensor technology

There are wide variety of occupancy sensor technologies available in the market, each of them holds their own advantages and disadvantages based on their features and functions. The predominant and decision factors to choose the sensors is based on the accuracy, affordability and scalability (Tianzhen Hong, 2013). The combination of both hardware and software is required to implement the occupancy sensor and the new age occupancy sensors holds the automatic adjustment to avoid the false detections.

2.8.1 Making sense of sensors

The preponderance energy saving tool in the commercial building sectors is the lighting which accounts for 30 to 50% of the buildings energy consumption (Andersen, 2009). The action of turning off the additional lights can possibly reduce the direct energy consumption by 45% and that reduces the energy costs and environmental impacts (B. Raphael, 2007).

The occupancy sensors are the motion detectors that incorporate the timing device in it. They finds applications in control engineering, with which we can able to measure the indoor environment parameters (Heng-Tao Wang, 2010). There are different types of occupancy sensors based on the commercial applications. The further topics aims to discuss the OS types, their applications and future advances of this field.

The recent types of occupancy sensors with security systems actually refined and enhanced from their usual process such as controlling lighting systems and HVAC in commercial building sectors. The new age OS are integrated with the BAS and CS, this made them most popular and they're widely used in commercial building sectors (Peter T. Szemes, 2011).

2.8.2 Types of technologies

There are many types of sensors available in the commercial market, there are many selection criteria available and they are compatibility, daylight-Level Equipped, failure Mode, Indicators, Timers, Manual Controls, and Minimum Load. There are some secondary consideration and sources should be made in the field of selection and they are warranty, coverage (Brian Pilkington, 2011).

The available types of occupancy sensor technologies on the markets are Infrared or Passive Infrared (PIR), Ultrasonic or Ultra Sound (US), combination of both technologies as Dual Technology sensors (DT), Microwave, Audio sensor.

Infrared or Passive Infrared (PIR)

The PIR sensor is tuned to find and observe the infrared radiation (Heat) from the occupants. The PIR sensors are good at finding the major motion, they are capable of measuring only movements in the line sight and sensitive to the sidelong or lateral movements. PIR sensor usually used in the small area such as conference rooms, stores and warehouse. The range of the PIR sensor is 15 feet (App) and they don't consume energy since they are passive (Electric Power Reserach Institute, 1987).

They have a piece of lens which divides its coverage areas into positive segments and that is capable of detecting infrared radiations. Advantages of PIR sensors are highly resistant to the false triggering, they don't emit ultra sounds, and they quite inexpensive.

Ultrasonic Technology Sensors (US)

Ultra sensors are really good at detecting the minor motions (like typing or reading) form this we can assure that these are the most sensitive sensor available commercially. Unlike the PIR they don't need any unobstructed line of sight to detect the motions. They are recommended to work within the large areas, open offices, hallways, and unusually shaped areas (Y. Song, 2013). The range of US sensors is extends from 23 to 32 feet

The US sensors contains both US generator and receiver, but they are more expensive than PIR sensors, they have a tendency towards the false signals; the overlapping of multiple sensors should be because the US experiences the hearing aids which results in reducing the effectiveness (Peter T. Szemes, 2011).

Dual-technology Sensors (DT)

The combination of both PIR and US sensors is called Dual technology sensors, they are designed with an aim to increase the reliability and accuracy. They usually used in the areas where they expect to achieve the high degree of accuracy. The range of the DT sensors varies up to 35 feet.

Microwave Sensors

These are the sensors that detects occupancy rate by emitting microwaves, the movements of the occupancy is detected through changes in the reflected frequency. The microwave sensors have both microwave generator and receiver, they have coverage and highly sensitive. They are only used for specialized applications and it's costly when compared to other occupancy sensors.

Audio Sensors

The name itself explains clearly that they special purpose sensors and activated by voice. The audio sensors have an inbuilt microphone that detect the sound made by the occupants or instruments. They are comparatively inexpensive and do not emit any noise but the audio sensors are readily affected by the factors other than occupancy and they do count them as a occupancy sign. They are suitable for the shaped areas.

Thermal Imaging Sensors

The thermal imaging sensors uses the array of sensors which is mounted inside the protective case and that is capable of protecting them from the ambient temperatures up to 60°C, dust, and smokes to increase the accuracy. They are capable of sensing -20 to 300°C, offers online monitoring. They are powered by the embedded technology and capable of delivering high level of accuracy up to 98%.

D Camera Technology

It is powered by the video cameras and supports the online monitoring which supports the software that are capable producing the occupancy in 3D vision. They achieve the high level of accuracy with 98%. The main drawbacks of this systems are high cost, high maintenance cost.

Mobile Applications and Key cards technology

The new age of occupancy tracking is possible using the mobile applications, the available of mobile phones makes it simple and quick. With the help of software's in the mobile platforms coupled with the Wi-Fi and 3G & 4G network options it's possible gather the working site occupancy information's.

Then by using the GPS, the locations can be recorded and navigated accurately, moving to the key cards/ smart tags technology which is widely used in the commercially in the office sectors. It is used as the entry level sensors in the office sector, though they cannot be used as the fictional tracking device but inserting/ placing the appropriate key cards plays a vital role in monitoring the occupant within particular limit. The main drawbacks of this systems is privacy problem with the occupants but integrating this technique with the BAS would achieve effectiveness.

2.9 Efficient generation & productive usage

There is a substantial impact on the energy performance of the building which is due to the control related behaviour of the occupants (Hancock, 1992). This becomes highly important when the buildings are designed with an aim to push the occupants to interact with the building controls using adaptive model of thermal comfort (Kofmehl, 2012). From the research results it's proved that the determination of tolerable thermal condition within the indoor environment would result in indicative energy saving and has no effects on mental performance of the occupants.

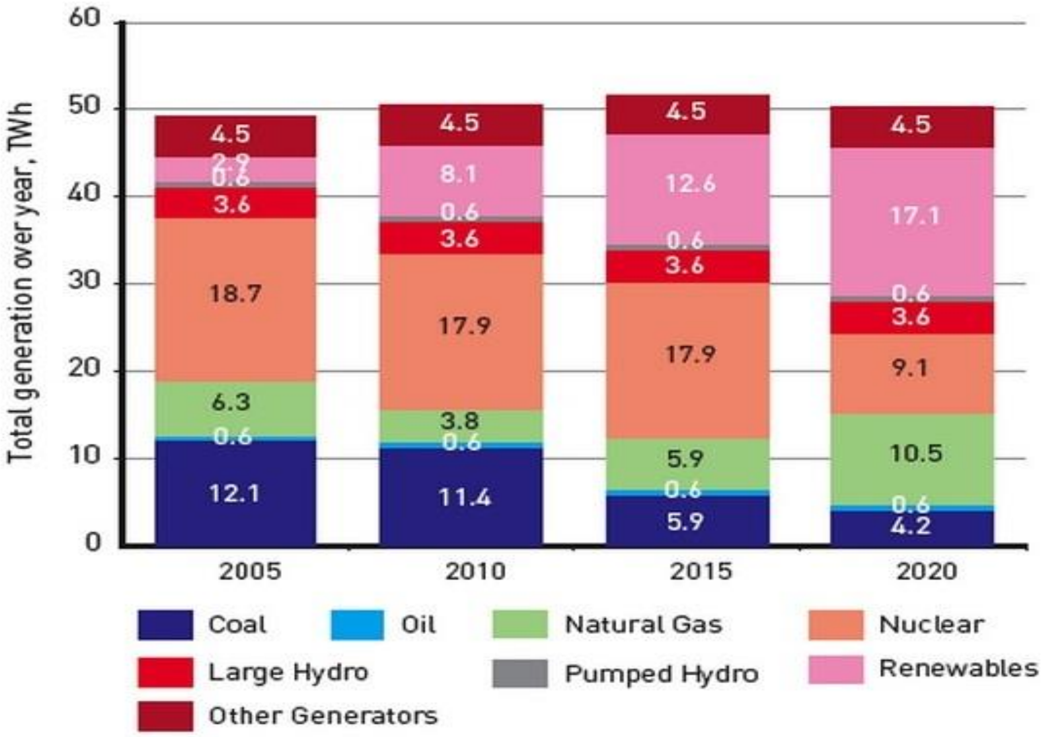

Figure 4- Projected Generation for 2020 (ECUK, 2013)

There will be a loads of differences in the behaviour of occupants between the multiple zones of the buildings. Time of the day is one of the main factor that shows a great impact on the behaviour patterns of the occupants. The predictions can't be made alone by only considering the environmental variables instead including multiple variables like thermal comfort, perception of air quality, secondary variable of occupants, physical variables of the buildings and other IEQ variables (Pieter de Wilde, 2012).

Tuning the set points with proper scheduling, isolating the wasteful equipment's and cognitive act on building trends will bring the productivity coupled efficiency. Thereby following the above discussed steps with marking the importance of the discussed variables would achieve the efficiency and meanwhile productivity.

2.9.1 Smart buildings and the Building automations

Initially the smart building is nothing but the basic form of building with installed BAS in it (Hancock, 1992). Which controls and monitors the building functions to maximise the energy efficiency and to minimise the maintenance cost. The new age smart building is the combo of BAS with integrated IT systems which is capable of performing multiple control operations. They also allows the user to perform some specific operation with the help of smart tags (LAUSTSEN, 2008).

The main objective of the smart buildings is to save energy and to have focus on building resources (Elsadig, 2005). The combination of multiple technologies that improve efficiency and interconnect building features to communicate with the users through the automated systems and this makes them smart, green and yet powerful building of the future. The research are in line to control the energy consumption within an indoor environment which is completely based on the occupancy profile within/ around it (Jessica Granderson, 2009). The effective and new range of BAS controls the energy consumption by occupancy tracking and this remains a big question mark due to its universal adoptability.

The smart building is always associated with the fault tolerance and this is the major element of artificial intelligence (Andersen, 2009). The potential of this concept and the surrounding technology is really vast, which finds impacts within the working environment and immensely varies as information varies. Furthermore work to develop responsive architecture will bring up the universal adaptability to environment that we live in today (Shuai Li, 2012).

2.9.2 Smart Buildings and Smart People

*"People want to engage with the controls rather than feel at the mercy of a technological hand of God" (*Simon Erridge)

The most important aim of the smart buildings is to evolve and to adapt to their occupants needs (Brian Pilkington, 2011). So it has become the custom for the designer to incorporate the effective part of occupants during the designing stage and that would allow them to have a control over their indoor environment. To improve the living conditions, the smart buildings should response to their occupants and their actions (Dixin Liu, 2013).

Though the smart homes are there for decades and decades, they haven't made any positive impacts to their occupants. One of the main reason for that is the misalignment in the objective and hypothesis between the Occupants and the designer. To avoid this issue and to prove effectiveness in the field of Smart buildings the technicians like, smart technologist and architect should stop anticipating the things ahead and start including the occupants at the age of designing process (Shuai Li, 2012).

In the case of retrofitting the smart technologies in to the existing buildings the main consideration should be kept on the occupants and should provide appropriate service. They should associate with clients and should work closely as a collaboration to enhance the creativity and aims to smart buildings

2.10 Similar studies

Measurement & Analysis of High resolution data in order to monitor occupancy numbers within an indoor Environment

A similar study carried out at the ESRU and Department of Mechanical & Aerospace Engineering in the University of Strathclyde, to set out the equation which allows to track and predict the occupancy pattern. This paper analyses the indoor environment parameters such as temperature, humidity, lighting, audio and motion levels using the multi-parameter regression analysis. The methodology & Test location used in this paper was similar to that carried in my project. The result of this project seems to have lag in accuracy due to the addition and assessment of 5 parameters and that is more obvious from the indicated time steps (Pert, 2013).

Predicted vs. Actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap

A similar study incorporate the same focus of evaluating the post occupancy performance carried out at the Centre for Innovative and collaborative construction engineering in the Loughborough University, this paper explains the causes of inconsistency between energy modelling predictions and performance of occupants. This paper analyses the casual factors and parameters regarding the occupancy behaviour. The results of this paper clearly explains the importance of POE and brought an accuracy of 3% to their model by combining the monitoring data with predictive energy modelling (Anna Carolina Menezes, 2012).

Pre Heat: Controlling Home Heating using Occupancy Prediction

The aim of this paper is to efficiently heat the homes by using method of occupancy sensing and occupancy prediction. This research was partly based at the school of computing & communication engineering in the Lancaster University and Microsoft Research, Cambridge. Their paper uses the statistical approach as similar to this project, which is aimed to predict the occupancy in relation to the actual gas consumption. The result of this paper achieves the decrease in pre-heat by the Miss Time factor of 6-12, while consuming the same amount of gas and that is due to the occupancy based prediction algorithm (James Scott, 2011).

2.11 Summary

The literature review briefly inferred the future research into sustainable built environment especially in the commercial building sectors. Further, the BEMS, its application in the commercial buildings, occupancy behaviour was studied emphasizing its impacts in the energy consumption. Finally occupancy sensor technologies and its types in market are studied within the field of BAS. This piece of review really helped the research and made me familiar with some relevant systems. Towards the end, the reviews of similar studied and their pattern of defining the problem really helped in fixing the background problem. Moreover, the literature review was also used to support the research made in the analysis.

The detection of headcounts within a building is failed sometimes in terms of some parameters which is due to the package of missing data, on where some predictive methodologies should be used to match them, hoping the investigation made in the further chapter would bring some changes in applied methodology.

3. Methodology

The research work in this projects involved several steps, most of them are of statistical based analysis that is aimed to predict and address the accuracy of the occupancy profile. The methods and its functions involved in this analysis will be discussed in detail.

Further this chapter will scrutinize the methods employed in this research to predict, identify and to set the occupancy profile. The detailed view on the experimental site, their specifications, and material used such as instruments details will be seen with proper evidences. Data collection process, types of data's and steps involved in collecting them will be discussed with the referred methodology. Further the methodology speaks about the data analysis techniques, level of analysis and details on tools that have been used in this research such as CA and MRA.

3.1 Experimental Site

As this research is mainly focusing on the commercial and service buildings, their total energy consumption for the year 2012 is 19% which was 14% in 2011 and expected to arise in the following years. Since the commercial and service buildings sectors are fast growing in nature so their energy consumptions are expected to bring a drastic environmental changes which is totally unhealthy for the current scenario. Consciously keeping these issues in the mind and in order to provide a most responsible result which could be used as the dominant factor for the future research. Keeping all this factors in mind and to make contribution for the University, the University faculty office place is selected as an experimental site.

3.1.1 Site & Specifications

The experimental site for the research project was the Energy Systems Research Unit (ESRU) which is within the University centre located at University of Strathclyde. The office is a wide open plan which is in the 2nd floor with multiple research offices running within it, coming to ESRU's specifications as said earlier it is an open place with multiple desks, couple of meeting rooms and a passing place with kitchen and rest rooms. The place is filled with research faculties from ESRU, further the office place is extended and ends with different research offices like Fraunhofer UK (Centre for Applied Photonics) & weir Lab. It's clear from the site specification and as observed the office is usually quiet and out from the noise pollution other than formal phone calls.

The office place is evenly distributed and monitored by the “Be-spoke” multifunctional sensors which is powered to collect the indoor environment real time data on temperature, relative humidity, lighting, audio, and motion. In order to avoid the data traffic conflicts the sensors are evenly distributed around the office. To make this process of collection easier, the office plan has been divided into five zones. The office plans, sensor positions, and zones specifications can be seen in the below figures.

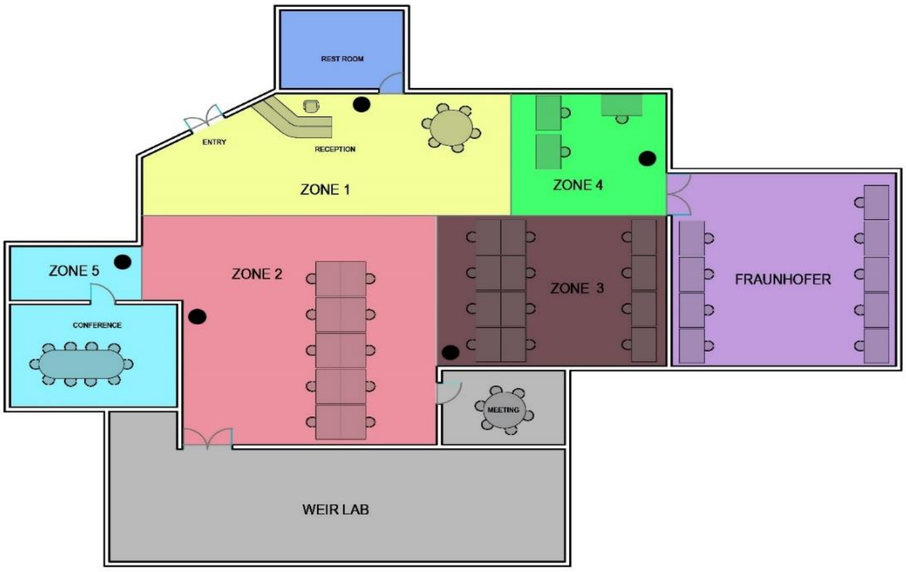

Figure 5-Experimental Area- ESRU Strathclyde

3.1.2 Be-Spoke Multifunctional Sensor

As discussed above the ESRU-Office space is evenly distributed by the “Be-Spoke” Multifunctional sensors which is designed and exported from the Newcastle University’s Digital Research Hub. Were it has been employed to estimate the occupancy level by monitoring the indoor environment data’s like Temp., RH, Lux, DB, and PIR. The combination of highly powered physical and virtual sensor would help in reducing the energy consumption within the buildings. Deployment of high range Bespoke multifunctional sensors helps in gathering the data’s that are required to assess the thermal comfort of the occupants which in turn resolves the major conflicts that causes the unwanted wastage of energy.

Zones	Sensor Numbers
Zone 1	S: 0110
Zone 2	S: 0072
Zone 3	S: 0091
Zone 4	S: 0071
Zone 5	S: 0082

Table 1- Zones Details

3.2 Data Collection Process

Data collection tends to be one of the main part of this research because they produce meaningful data's that make sensible approaches to resolve the unwanted energy consumption in the buildings by analysing the occupancy behaviour. Further to the investigation the data's collected by the sensors are stored within a MySQL database. The datasets are programed according to the analyst need.

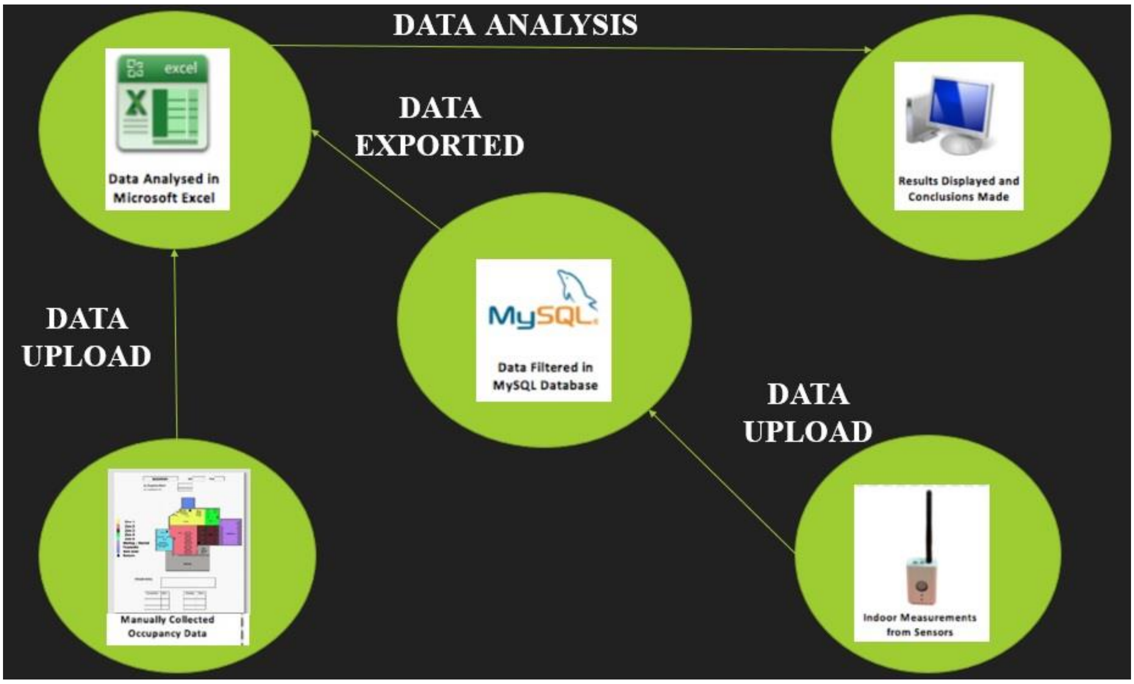

Figure 6- Data Collection Process

The process involved in data collection are quite straight forward, the methods, materials components and software's involved to do this process are bulleted below with the steps.

- The Bespoke Multifunctional sensors: It is used to sense the indoor environment data’s and the measured data’s are uploaded automatically to the MySQL database in a period of all days in a week (24/7).
- MySQL: The data’s gathered from the Bespoke multifunctional sensor is filtered and then stored in the MySQL database. The stored can be used for the data analysis work which is capable of predicting the occupant behaviour. The datasets can be varied (in Time steps) according to the need of the researcher by reprograming with corresponding time steps
- MS Excel: The required data’s that are to be analysed are exported to the Excel sheet.
- Occupancy Measurement form: Manually collected occupancy data’s from all different five zones exported into the Excel sheet. The details on Occupancy data collection will be explained further in detail as under.
- PC/ Laptops: Analysis performed using Excel sheet, the result and the conclusion were made accordingly.

3.2.1 Indoor Environment data’s

The Bespoke multifunctional sensors capable of measuring 5 parameters for every six seconds and they are deeply discussed below:

Air Temperature (°C)

The air surrounding the body is usually called as the Air temperature. It is raised due to the effect of external factor like amount of heat from the electrical appliances, ambient temperature. The air temperature is measured in degree Celsius. In case occupancy measurement they have some of impact when the occupants are increased in counts. They also act as supporting factor in case of setting occupancy profile.

Relative Humidity (%)

Relative humidity (Ø) is defined as “the ratio of the partial pressure of water vapour (**e_w**) an air-water mixture to the saturated vapour pressure of water (**e^*_w**) at a given temperature”. The relative humidity is purely depends on the air temperature and total pressure. They are consider as the supporting factors in the scenario of measuring level of occupancy.

Lighting (LUX)

The luminance is the measure of amount of flux spread over the given area. Usually the light illuminate more dimly in the open office area, since it's a large area and illuminance are inversely proportional. They have powerful impact on assessing the occupancy level and so considered as one of the dominant factors.

Audio (dB)

The bespoke multifunctional sensors are capable of delivering the audio signal as a packets of 24 individual 'samples' for every six seconds. Which is further refined according to the analysis process, it is usually measured over the frequency of 4Hz.

Motion (PIR)

The operating principle of the PIR sensor is that all object with a temperature above 'absolute zero' emits heat energy in the form of radiation. It's clear from the principle that the PIR detects the level of occupancy passively using the infrared radiation as a source. It's same as audio the data's are collected as 24 individual packets. The motion sensor commonly called PIR or PID.

3.3 Data Collection Form

The data collection form is designed with an aim to observe the occupancy level within the five zones, additional activities like shift of occupants between the zones for every five minutes to identify their position, No. of laptops/computers On for the particular time. The manual collection of occupancy level and their behaviours for all zones are really helpful in analysis part. The process of data collection has been carried out for 2 working days and weekend data's has been gathered from the MySQL database.

The design includes floor plan with position of the sensors, there are multiple tabs to enter the details of the occupants, No. of computers Kept on, Ambient temperature for seasonal approach, Date, Time, other noticeable activities to identify the occupancy behaviour impacts. Data collection form plays a vital role in analysis part, the observed occupancy level is then imported and merged to the Excel sheet were these are regressively analysed using the statistical model which will be discussed below in detail.

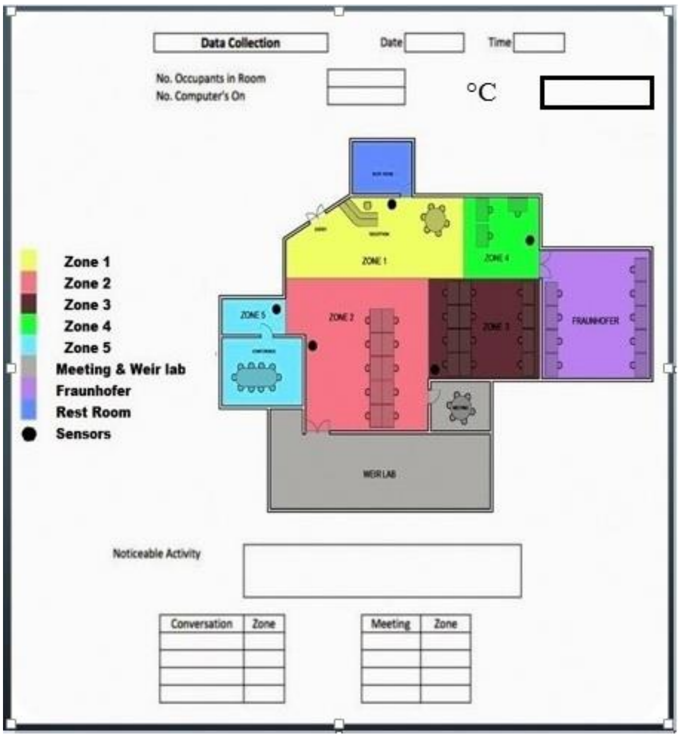

Figure 7- Data Collection Form

Data Collection

It is the most important level in this research, the data collection process involves multiple levels like weekday collections, weekend collections, and experimental observations. The data collection process was meant to be a great opportunity to learn and observe the occupancy behaviour, their shift and usage of electrical devices and that gave a better understanding to resolve the impacts.

Weekday Data Run

According to scope of this project, the weekday data collection has been worthy enough to gather and observe the data's. It has been a great platform to test the sensors viability and accuracy of the data. The data's were collected on Thursday 1st of August for 10 hours from 9.30am to 7pm, the manual counting of occupancy was achieved for every 2 minutes along with the occupancy behaviour observations. Similarly, to try approaching the seasonal variation and to know about the effects and impacts on the particular month. The data's were taken over the course of the 26th, 27th, and 28th of February which is said to be to winter.

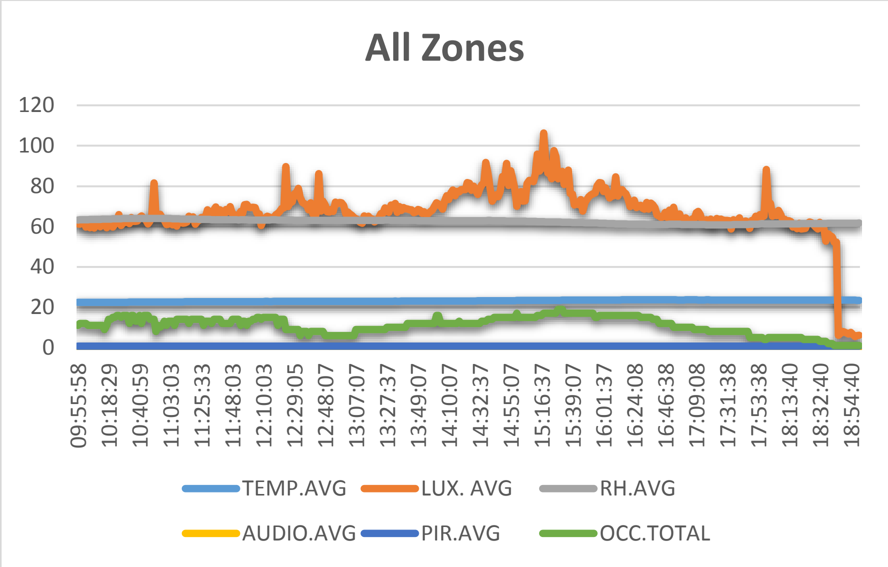

Figure 8- Collective Measurements from All Zones

The above Fig shows the collective parameters from all zones, which is plotted with respect to the time. The data's found to have a great relationship between each other and also with the observed data which will be explained in data analysis topic.

Weekend data Run

The collection of weekend data is the part of the research to observe the weekend effect when the building was unoccupied. In the same way the data's for five different zones were collected on five parameters, on gathered 17th (Saturday) and 18th (Sunday) of August for 24 hours. In order to study the variation using seasonal approach, the data's from previous studies have been used, that is 23rd of February which was autumn.

Experimental Observation

To explain the experimental observations made on 1st of August for 10 hours from 9.30am to 7pm, the headcounts was manually collected for every 2 minutes in all five zones. The effect of occupancy level on other five parameters are deeply explained in the next chapter with more appropriate situations.

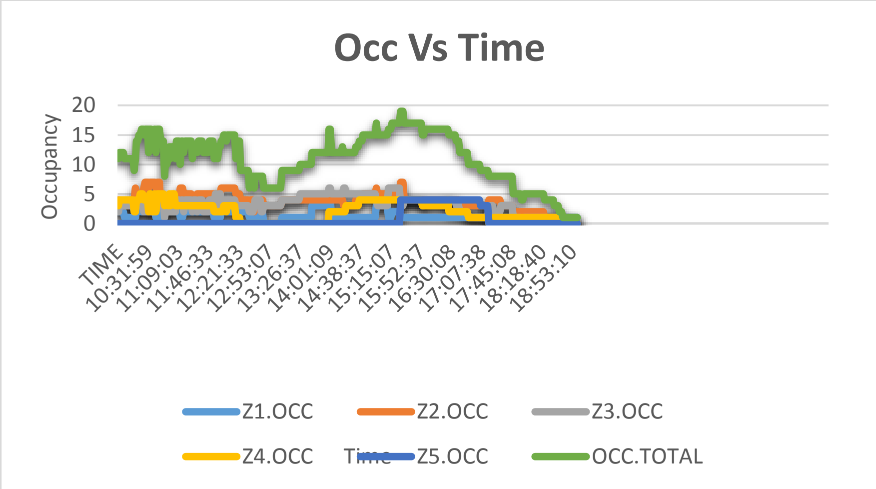

Figure 9- Occupancy Levels- Experimental Observations (1st of August 2013)

From the figure, the horizontal axis is of time (10.3am to 7pm) schedule and the vertical axis is of occupancy. The occupancy levels of all five zones with respect to their total can be seen and the drift and ripples between the zones explains the shift of occupants from one zone to another.

Data Arrangement

Since the project deals with high resolution indoor environment data, it is important to optimise them according to the applications. The significance of data optimization is initial transformation in quality of data that is being collected. Applying the data optimization helps in scaling and tuning the data's that was collected during the experimental season. It would be highly impossible to perform the analysis technique without optimizing the enormous amount of data. The reduction in time steps makes the data optimization process more elusive than before because the figure of each parameter was 2 minutes. The actual size of the data was 4,200,238 individual cells from 5 sensors for 4 days.

Time Scale	Temperature °C	Average
9.30 AM	22.68	-
9.32 AM	22.69	-
9.34 AM	22.7	-
9.36 AM	22.85	-
9.38 AM	30	= AVG(22.68+22.69+22.7+22.85+30)= 24.184

Table 2- Data Arrangement Process

In meantime the unwanted data are omitted and cleaned from the content. When looking into the parameters like AUDIO and PIR, they are received in packets of 24 samples. Filtering and arranging them was quite challenging. Importing the observed data into the worksheet with proper reference requires a round off methods.

3.4 Data Analysis

Since this research work deals with high resolution data's from multiple sensors that are capable of delivering the missing packets and it's become important to use multiple data analysis to determine the significance of the process. The correlation and multiple regression analysis used as a data analysis tool.

The analysis is to be split up into multiple stages:

1. Applying the correlation analysis for the multiple zones. Use WEEKDAY data.
2. Applying the comparison analysis for the multiple zones. Use WEEKEND as well as WEEKDAY data.
    - Comparing the indoor environment parameters with each other over two different seasons
    - The weekend data's are treated as AMBIENT data's and deducted from the weekday measurements to perform the MRA
3. Calculate the total room occupancy over the course of WEEKDAY.
    - For individual zones using the measurements from all sensors.
    - Comparing the data's using Seasonal Approach.
4. Calculating the predicted occupancy levels & Residual using's Multiple Regression Analysis. Course of WEEKDAY.
    - For all individual zones using filtered values of exact path set.
    - Comparing the actual occupancy level vs. predicted occupancy level.
    - Testing the pre-defined equation's certainty level with the real time data.
    - Finding the new regression equation with more accuracy

Correlation Analysis

Initially all the indoor environment parameters are filtered and sorted according to their zones limits. It is important to use the correlation techniques before applying the multiple regression analysis. The CA and MRA are related to each other, they both deal with interrelationship among the variables. The linear association between two variables are clearly measured by the CA and that gives the enough confidents to go-ahead with the MRA.

The CA Coefficients are capable of measuring the exact relationship between the multiple variables and can identify the level of association between the variables. All these measurements would only represent the degree of their association between the variables and tell us significance of that association.

Multiple Regression Analysis

From the result of many technical discussion with the faculties of mathematics and statistics department within the University of Strathclyde, it was decided to undertake the MRA tool. Initially, this research was framed to apply and deal with the machine learning tool such as "Regularised Linear Regression Analysis" but due to its complexity, it was advised to undertake MRA. Later this data analysis work of applying MRA to predict the value of occupancy was helpful and provided the expected result with the great accuracy.

MRA involves in identifying the relationship between dependent variable and more independent variables. MRA is quite helpful in predicting the data range accurately when suitable independent variables are used with proper observations. Theoretically, the MRA is based on the following assumptions and they are linearity, independence, normality, and homogeneity of variance. The MRA is carried down using the Data analysis tool that available within the Excel worksheet.

The MRA has multiple number of outputs associated with it and the most important among them were discussed below:

R^2

R^2 is the one of the most important number of output. This output precisely explains the how the real data is being approximated by the regression line and it also explains in number that how much of the output variable variance explicated by the input variable variance. It is preferred that these values should at least be around 0.6 (60%) or 0.7 (70%).

Adjusted R^2

The accuracy of the regression equations is based on this values. Unlike $\mathbf{R^2}$, it is highly resistant. It predominantly increases with the accuracy of the regression equations which is due to the addition of new variables with high accuracy. Whilst they also increases even when the new variables are not accurate.

Significance of f

The values of f indicates the probability of the regression output attained by chance. So it's clear that smaller the value of f reflects higher the level of confidence on the chosen variables.

P-Value

It is similar to the value of F where the significance of f is considered for whole regression equations but the value of P is only meant for each input variable. So, the higher the P-value lower the chance of likelihood that the co-efficient or the Y-intercept is valid.

Residuals

The residuals is defined as the difference between the regression's predicted value and the actual value of the output variable (Observed variable). The regression equation is validated by the likelihood of having the more variable centred on the zero line in the scattered plot.

3.5 Summary

The methodology briefly inferred the methods and materials used in this research. The details on site locations along with the instruments used, their functions and the details on the data they deals with, that clearly contributes a main part in data analysis. Finally the data analysis works, types and their functions are explained would help in understanding the further chapters where the results are about to be presented.

4. Research Results

In order to predict and set the occupancy profile, the numerous analysis has been carried out and that gave multiple results to go discuss with multiple views such as multiple regression equations for multiple zones, predicated occupancy pattern as a graphical representation, comparisons of seasonal approaches and their effects. Further to the discussion in the methodology chapter, the results of multiple level analysis will be discussed below with proper evidences

Further this chapter will scrutinize the results obtained from the multiple analyses and aims to picture and table the obtained results with significant changes. In order to identify the best way to set out the prediction of occupancy level, this chapter mainly focused on the most significant results. The results of correlation analysis for the weekday data was performed as stage 1 analysis, the comparison analysis between the weekend data for multiple seasons are presented as stage-2 results, the results of occupancy pattern over the course of weekday for all zones with seasonal approaches is presented as stage-3 results, and the stage-4 result is from the MRA which clearly analyse and presents the predicted occupancy level as a regression equations and pictures the relationship between the observed and predicted occupancy level coupled with the residual relationship.

4.1 Stage 1: Correlation analysis for weekday data

Using CA is the initial step of this analysis, this statistical technique clearly shows the strong interrelationship between the variables. Performing this CA builds a greater understanding about the data sets. Since this research deals with high resolution data it is obvious to perform the CA before proceeding further analysis. The analysis is further performed for all the individual zones within the test location, in addition to the interrelationship knowledge the CA is really helpful in avoiding the unwanted data's that affects the regression process.

Correlation	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**
Occ. Vs. Temp.	0.010629	-0.307734	-0.154777	-0.174941	0.55964
Occ. Vs. Lux	0.102163	0.5567474	0.6019517	0.2512685	0.19364
Occ. Vs. RH	0.099016	0.4121526	0.1506600	0.2731775	-0.29897
Occ. Vs. Audio	0.135976	0.1793223	0.1056126	0.2754326	0.718476
Occ. Vs. PIR	-0.00836	0.0505789	0.0507846	-0.080578	0.232289

Table 3- Stage I Results: Correlation analysis for all zones

The result of the CA indicates all the five parameters of five zones were all of them correlated against Occ. The result of the CA is called the correlation coefficient (r) that ranges from -1 to +1. The values that fall under this range shows their strength of relativity between each other.

Table 3 indicates the correlation coefficient with varying order of relativity, the order of relativity is prioritised as a picture and that can be seen in the Fig 9. Though the results turned out to be in order that shows the effect of motion (PIR) is merely low, it is taken into consideration and cross analysed in the next stage using MRA.

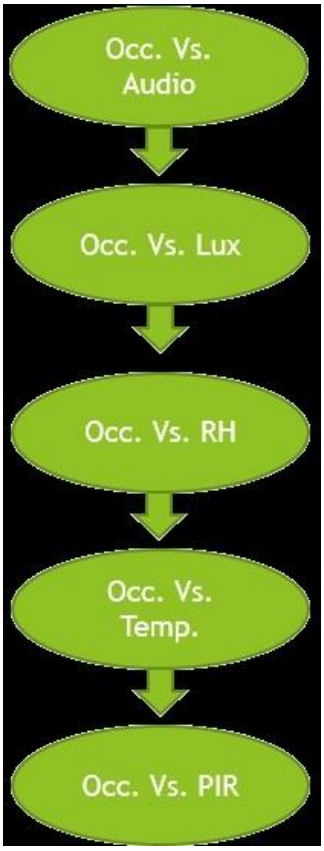

Figure 10-Order of CA coefficient

4.1.1 Stage 2: Comparison analysis

The comparison results aims to present the relationship within the indoor environment data more graphically. This analysis pictures and compares the impacts of individual zones with all parameters. The major source of impact that is the behavioural analysis is well explained in the next stage. The same sort of prioritization is followed in this stage.

The multiple variable comparison along with the seasonal approach will give an intense knowledge based on their variations which might due to the effect of indoor environment.

4.1.2 Comparing the level of Audio

The Fig 10 shows the comparison on the level of audio within the built environment which clearly varies with time and found to have many ripples due to the internal and external impacts.

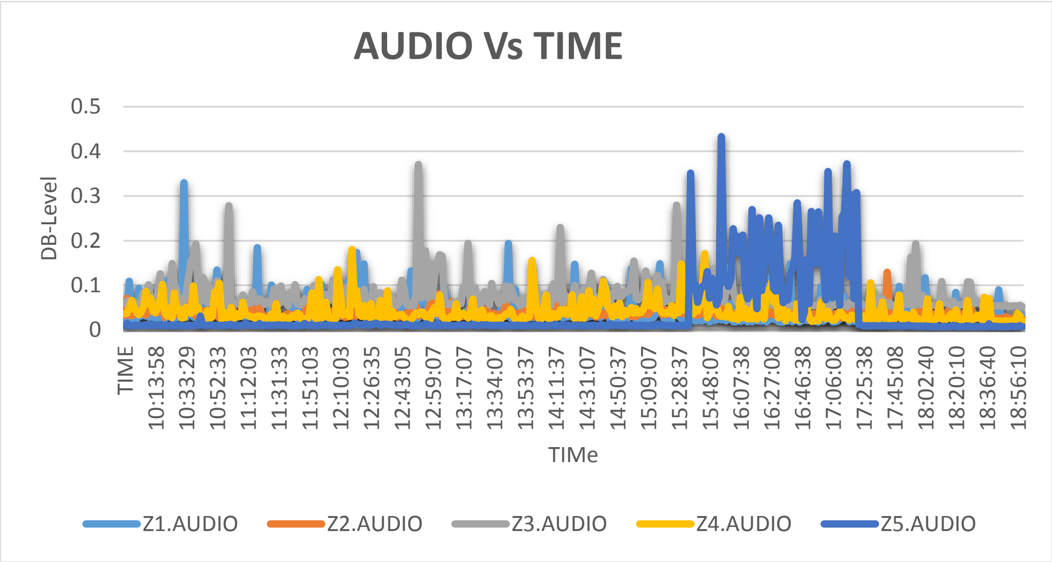

Figure 11- Level of Audio for all zones

The blue line (Zone 5) touches the peak for 1Hr and 18minutes from 5.48Pm to 7.06Pm. Which means there must be some sort of influences which will be deeply discussed in the behavioural studies.

4.1.3 Comparing the weekday data's

The fig 11 indicates the audio level comparison between Z3 and Z5 (Meeting zone) over the weekday (1/08/13). The orange line indicates the level of zone5, it was less or zero populated from 9.55am to 3.30pm. There is a drastic improvement in their audio level which can be seen from 3.30pm to 6.30pm which is due to the prolonged meeting. The blue line indicates the Z3 which is located in the middle section of the plan (Fig 4) and mostly occupied. The reason for the multiple number of spikes within the Z3 is due to their position and further impacts from the occupants.

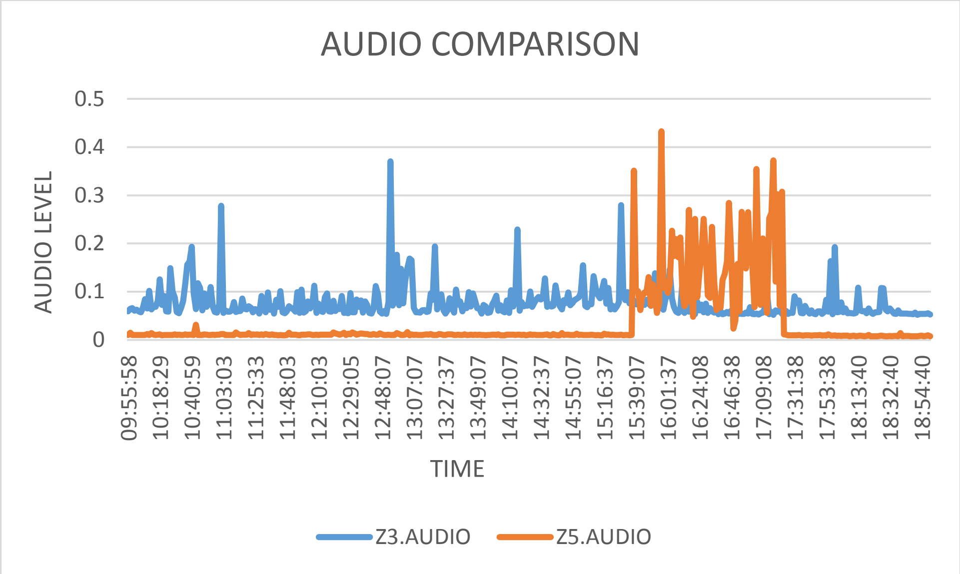

Figure 12- Audio comparison chart

4.1.4 Comparison between weekend and weekday data's

Fig 12 indicates the same audio comparison but this between the weekend (17/8/13) and weekday (1/8/13) data. From the course of comparison it's obvious that the level of audio is quite sensitive and acts readily on interactions.

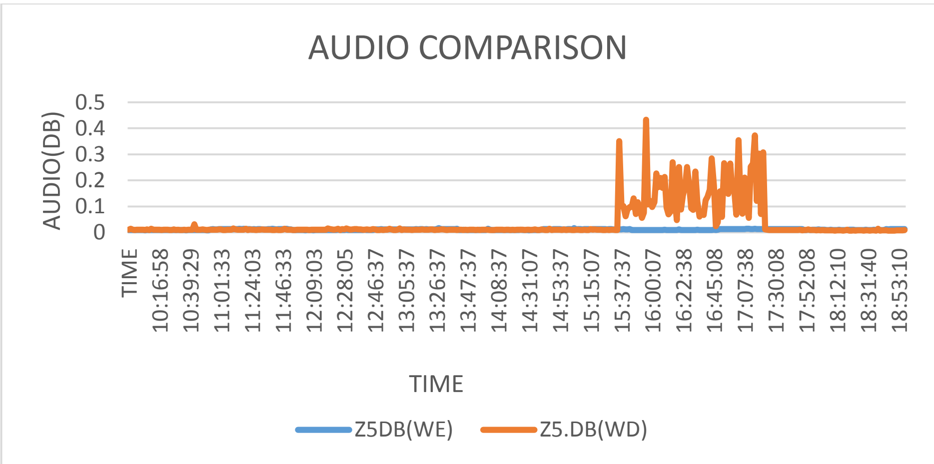

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Figure 13- Audio comparison b/w weekend and a weekday data

The blue line is almost zero with no spikes which is a weekend data and the orange line indicates the weekday data with spikes during 3.30pm to 6.30pm. It is obvious from the comparison results that all the parameter will have some sort reaction due to the human interaction which will be discussed below.

4.2 Stage 3 – Behavioural Analysis

The behavioural analysis would be helpful to understand the basic and minute factors that cause changes inside the buildings in terms of occupants and their activities. The aim of this analysis is to find the cross effects from the behaviour pattern inside the buildings. Hopefully these findings helps to justify the level of impacts caused by the occupants.

Looking on to fig 13 which shows the level of audio over the time duration, the values of each zone is plotted with the filtered audio level which is delivered as the samples containing 24 packets. Each of the zones used to collect 24 packets of its own, which is further processed and imported to proceed the analysis.

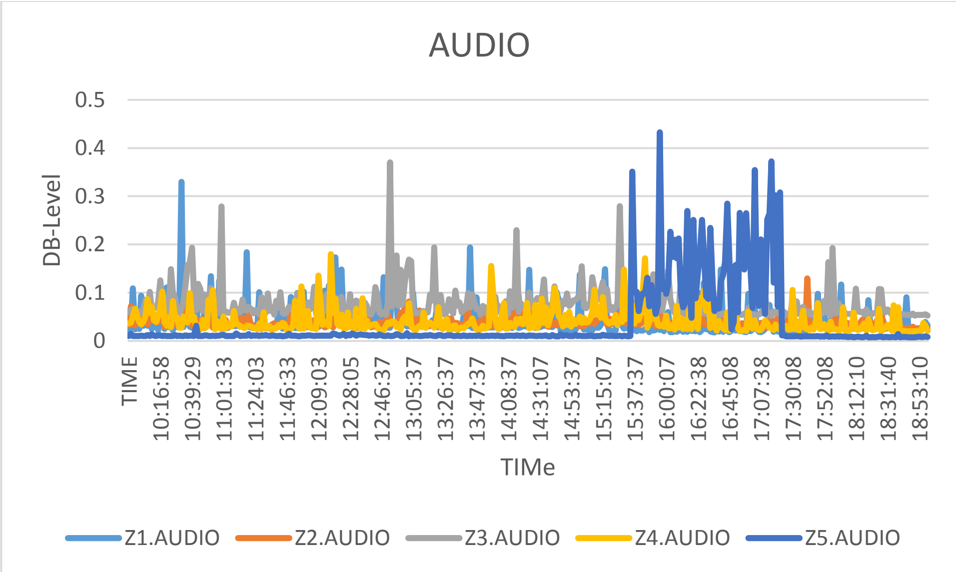


Figure 14- Behaviour Analysis Test on Audio level (dB)

In order to read the behaviour pattern and to find its relation between the each indoor environment parameters. The data's of different zones are compared with the occupancy level sequentially for every zone. The outcome of this analysis is presented in the fig 13. The blue line represent the level of audio in the zone 5, since the peak deflection is comparatively high in that region. Then on integrating the zone 5 audio variables with the appropriate zone Occupancy, gave an expected result and proves to have an exact match with the observed result.

Further to the above discussion, the Fig 14 indicates the result of behavioural analysis for the chosen parameter of particular zone. The orange line indicates the count of occupants (Observed data).

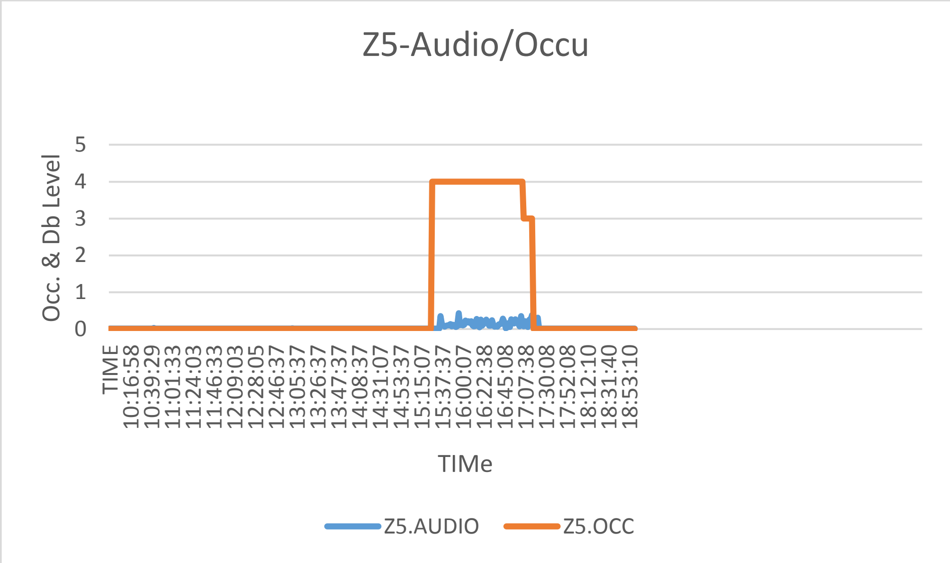


Figure 15- Behaviour Analysis Zone5 Audio Vs. Occ.

The blue line indicates the level of audio within the zone 5 which shows and reacts according to the changes in the occupancy level. The result of behavioural analysis motivates to move further to analyse the multiple variable, identify the dominant influential factor and to form a predictive methodology using MRA which continues as next stage of result.

4.3 Stage 4- Multiple Regression Analysis

Due to the positive appreciation from the previous analysis and also from the close by results with exact matching, gave an enough confidence to proceed towards the further work of predicting occupancy level within the built environment. The initial aim of this analysis is to identify and indicate the most important dominant factor, which would play an important role in the predicting and setting the occupancy profile.

In order to identify such dominant factors among the others and to develop the predictive equation, the statistical approach called MRA is used in this research. In addition to that, the predefined equation from the previous study has been tested rigorously using MRA.

The levels involved and their result of MRA is presented in detail which is of individual zone analysis coupled with the seasonal approach. The main results are of regression equations, further breaking them to identify the predicted occupancy levels which is presented below in graphical representation. The graphical representation holds the combinations of observed occupancy with the predicted one and also the residuals.
In a state of accuracy and to provide better regression equation with high predictive source, the analysis only considers the zone/parameter with high accuracy and deducts the rest of outputs from MRA which sounds unpredictable in nature.

Stage 1-MRA on a weekday

The MRA on a weekday was performed on Thursday 1st of August 2013, the corresponding data's have already been populated into the Worksheet, were the worksheet has an inbuilt data analysis tool. The processed data with equal number of datasets should be used to get the appropriate regression result. The analysis is carried down for all individual zones and that's aims in getting the five regression equations.

MRA on Individual zones

The MRA is performed on zone 3 with all parameters included. The fig 15 indicates,

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.6595263
R Square	0.434975
Adjusted R^2	0.4274211
Standard Error	1.1542605
Observations	380

ANOVA

	df	*SS*	*MS*	*F*	*ignificance F*
Regression	5	383.5975497	76.72	57.5835	2.44E-44
Residual	374	498.2866608	1.3323		
Total	379	881.8842105			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-21.76159	18.18301837	-1.197	0.23214	-57.51536	13.99217	-57.5153562	13.99217042
91TM	-0.376216	0.441483662	-0.852	0.39467	-1.244318	0.4918849	-1.24431771	0.491884939
91LX	0.2167886	0.013440746	16.129	8.4E-45	0.1903597	0.2432175	0.190359659	0.243217469
91RH	0.2972024	0.126717931	2.3454	0.01953	0.0480335	0.5463713	0.048033472	0.546371298
91AU	-2.852251	1.840947488	-1.549	0.12215	-6.472156	0.7676545	-6.47215571	0.767654467
91PR	16.931529	7.647735056	2.2139	0.02744	1.8935802	31.969479	1.893580164	31.96947882

Figure 16- Output of MRA for zone 3 (01/08/13)

Results of MRA on zone 3. There is a little variance between the R^2 and the adjusted R^2 values which means the output has little confidence for the predictions. The significance of ***f*** value is considerably low which gives better confidence for the predictions. The Equation 1 indicates the result of MRA on zone3 and the fig 16 displays the output residuals.

$$Y=4.495485-(0.7778*Temp.)+(0.00073*Lux)+(0.27095*RH)+(1.27519*Audio)-(1.7393*PIR$$

Equation 1- Regression Equation from zone 3

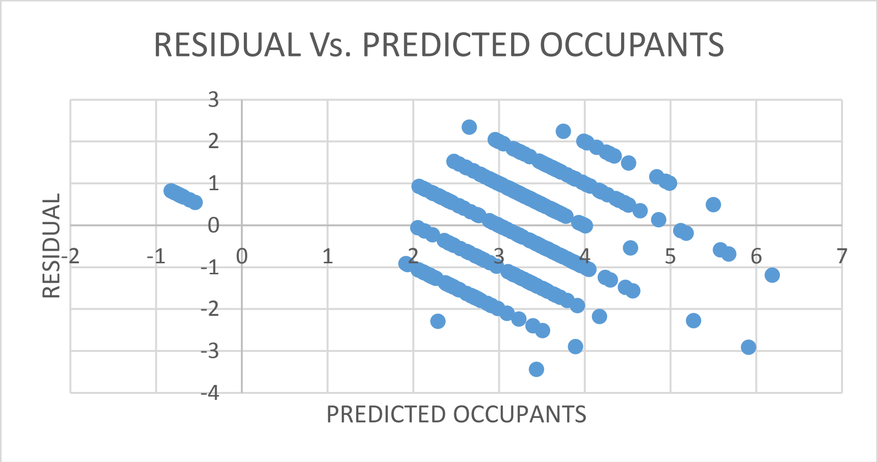


Figure 17- Residual output- stage 1

Zone 1	**Weekday Data**
$\mathbf{R^2}$	0.1883
Adjusted $\mathbf{R^2}$	0.1774
Significance of *f*	1.86E-15
Zone 2	
$\mathbf{R^2}$	0.4831
Adjusted $\mathbf{R^2}$	0.4762
Significance of *f*	1.65E-51
Zone 4	
$\mathbf{R^2}$	0.2127
Adjusted $\mathbf{R^2}$	0.2022
Significance of *f*	7.31E-18
Zone 5	
$\mathbf{R^2}$	0.7040
Adjusted $\mathbf{R^2}$	0.7001
Significance of *f*	1.49E-96

Table 4- Stage 1 Results

The table 4 shows rest of the result from stage 1 and their equations with output residual graphs are added up in the Appendices.

Stage 2 – Testing: previous study Equation

As a part of the analysis the regression equation obtained from the previous study was tested. The equation was derived on certain conditions such as treating the room as a whole and using measurement calculated by taking an average value provided from each of the 4 sensors excluding the zone 1 and the parameter PIR (motion).

$$Y = 122.148 - (1.096 \times Temperature) - (3.706 \times Humidity) + (0.024 \times LUX) - (69.939 \times Audio)$$

Equation 2- Previous study Equation

The equation 2 displays the predefined equation was based on the data's that have been collected during the February (26, 27, and 28) and that was winter season. Moreover the equation was purely based on data's from four sensors in a time step of 15 minutes interval, were this research deals with 5 sensors that provide high resolution data's in a time step of 2 minutes.

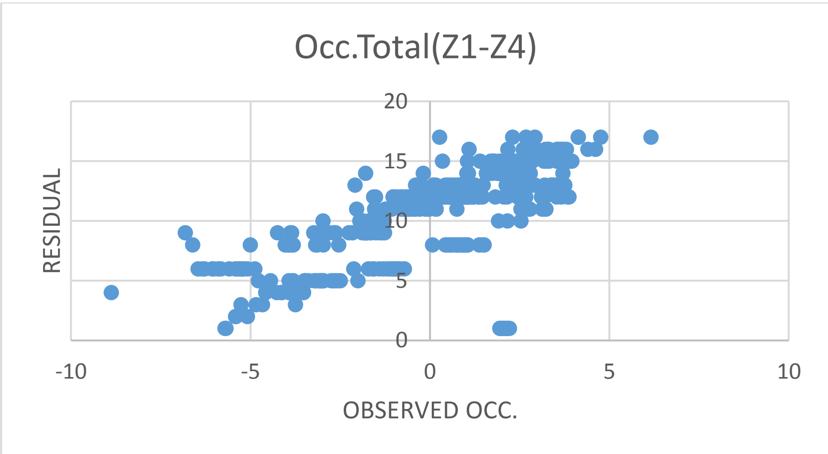


Figure 18-Residual Vs Occupancy pattern

The figure 17 explains the output results of (Z1-Z4) by the testing equation which was obtained from the previous study. It clearly highlights that no significant relationship is being calculated. Providing an optimal adjusted R^2 value of 0.47 and a majority of p- values are above o.5 and it would make no contributions by using this equation. The study has been carried down by switching multiple zones with multiple parameters in order to bring the most accurate regression equation out of different range.

Due to the following reason, the equation failed to prove its universal standard and can't be applied anymore to the other platforms.

Stage 3- MRA for the WHOLE plan

As a part of analysis, the individual zones are combined into whole room. Further on applying the MRA to the test location. The fig 18 shows the residual graph which clearly highlights that no significant relationship is being calculated.

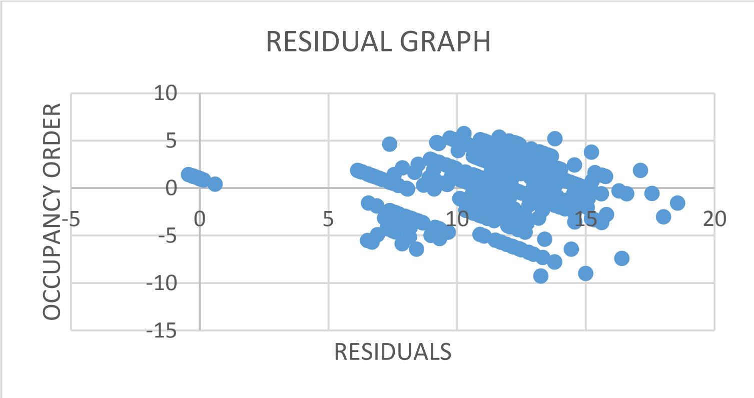


Figure 19- Residual graph of whole plan

Regression Statistics	
Multiple R	0.7014
R square	0.49203
Adjusted R^2	0.48524
Standard Error	3.08520
Significance of *f*	6.62E-53

Table 5- Statistical Results of Entire Room

From table5, providing an optimal R^2 value of 0.49 and majority of P values are above 3.0 which would make no contributions using this regression equation for the generalised model.

Stage 4- Seasonal approach

This time the MRA was applied on the data's related to the seasonal approach. The external ambient temperature was initially taken as 16°C which further varies from 16°C to 14°C.

Regression Statistics	
Multiple R	0.865495
R square	0.749082
Adjusted R^2	0.745046
Standard Error	2.171272
Significance of *f*	1E-108

Table 6- Statistical Results of Seasonal Approach

Table 6 indicates the most accurate result obtained from the seasonal approach, which was obtained by considering following criteria's

- The average of all 5 parameters collected from all individual zones were used.
- The observed occupancy profile from all individual zones were added up together to form a total occupancy.
- The external ambient temperature for the particular season was taken from the updated weather report.

The scatter plot below (fig 19) displays a very random relations between the residual and the occupancy order. Which indicates accuracy of regression analysis on seasonal approach.

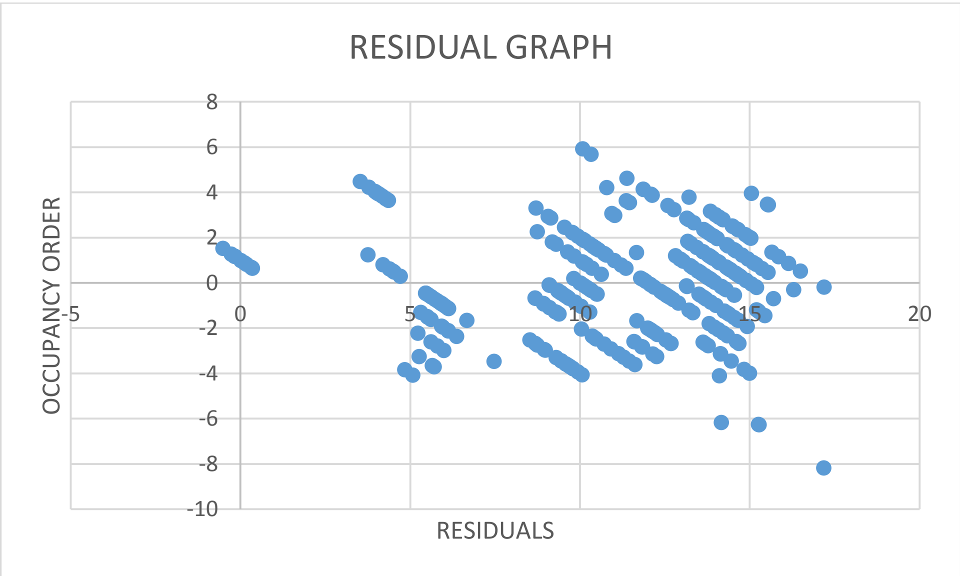


Figure 20- Residual graph for seasonal approach

The result on seasonal approach will be discussed and justified based on MRA coefficients and Equation in the further chapter.

4.4 Summary

The results section briefly inferred the results from multiple research works that includes analyses like correlation, comparison, behavioural, and MRA for the multiple zones coupled with the seasonal approach. Finally the prime parts of the analyses was presented as comparison figures, behavioural charts, regression equation and summarised tables. The most dominant factors that are identified from the results would be discussed and justified with proper evidences. Those justifications, arguments on identifying the dominant factors and their evidences for the most accurate result will be discussed in the further chapter.

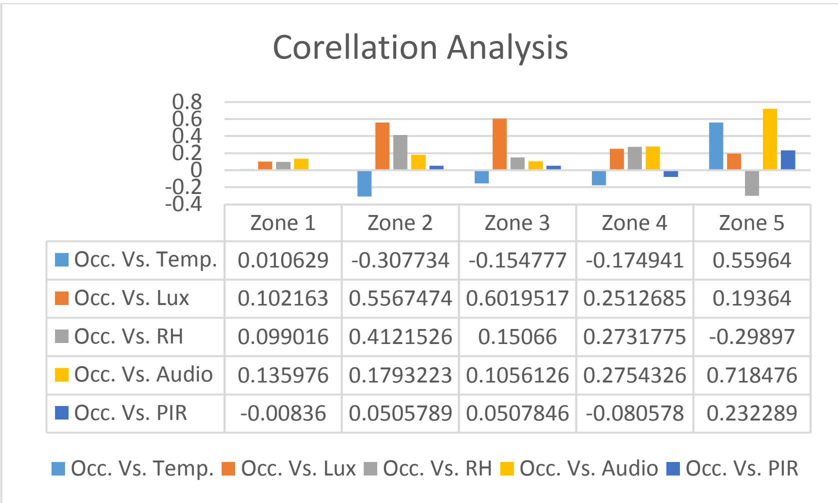
5 Discussion

The analyses used to predict, organise and set the occupancy profile within an indoor environment gave multiple results and that was clearly presented in the above chapter. The point of explaining the obtained meaningful findings and the judgement taken from the results would be discussed in this chapter.

Further this chapter will scrutinize the speculations based on the obtained results, the value of judgement and degree of chance on predicting the occupancy level will be discussed using the results from the previous chapter. The order of dominant factor is explained using the line fit plots obtained from the MAR and that would be one of the key findings from this research, on the other hand the viability of seasonal approach has been tested and the most accurate regression equation were explained.

5.1 Correlations Analysis

The initial aim of that analysis was to read the relationship between the multiple variables. The results from the fig 9 proves the capability of the analysis and that proves the relationship between the variables which is needs to be predicted. The order of prioritization shows the effectiveness of the indoor environment factors towards the occupancy level. That was the reported interpretation from the CA which gave the 1st order priority to the Audio level and then sequentially to the Lux, RH followed by Temp. And finally the PIR. This interpretation partly proves the position of PIR with the previous studies and thus justifying this results to be in line with the hypothesis.



	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Occ. Vs. Temp.	0.010629	-0.307734	-0.154777	-0.174941	0.55964
Occ. Vs. Lux	0.102163	0.5567474	0.6019517	0.2512685	0.19364
Occ. Vs. RH	0.099016	0.4121526	0.15066	0.2731775	-0.29897
Occ. Vs. Audio	0.135976	0.1793223	0.1056126	0.2754326	0.718476
Occ. Vs. PIR	-0.00836	0.0505789	0.0507846	-0.080578	0.232289

Figure 21- Justification from CA

Fig 18 indicates the accuracy of the CA which proves the strong relativity between the coefficients (r) the yellow lines indicates the relation between the Occ. Vs. Audio they’re all most close enough to the point +1 which further justifies their accuracy. Secondly looking into the orange lines (Lux), is also close enough to the scale of accuracy. Further the sequential order continues as RH, Temp. And PIR.

5.2 Comparison analysis

The principal of this analysis is to reconfirm those relativity between the variables by comparing the individual performance of the variables over different zones. The results obtained justifies the value of comparison and speculates the interpretation with proper evidences for each and every zones (Refer Appendix). Further this analysis was carried out as crossover study in which the indoor environment parameter was applied to multiple and sequential comparisons to comment on their impacts.

5.3 Behavioural analysis

This analysis was undertaken to study and identify the behavioural pattern inside the built environment. Since the experimental area had been divided into multiple zones it was really important to undertake this analysis. Which particularly concentrates on the occupants, their activities, impacts of their activities and how that cause the changes within the indoor environment. The observed parameters and the experimental data’s have been filtered and the behavioural analysis is carried down for each and every parameters for all five zones. Out of all the limited parameter that shows the exact variations were discussed in the results.

Fig 19 shows an example which explains the dramatic variations of the audio level according to the changes in the level of occupants. Were the blue cloud shows the occupancy level for zone 3 and the thin orange line shows the audible level. Hence once again it proves the level of prioritization is true.

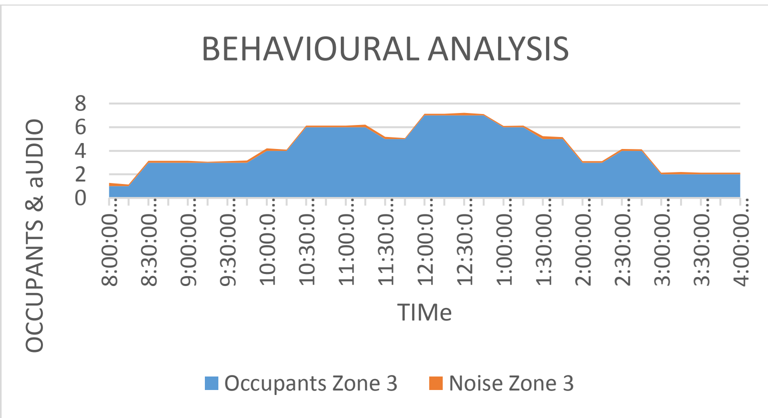


Figure 22- Result of Behavioural Analysis

5.4 MRA Analysis

Initially, from the analysis there were two close by results one was from the stage 1 and the other one was from the stage 4.

Stage 1- For the zone 5

The MRA is performed on zone 5 with all parameters included. The fig 22 indicates,

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.839088313
R Square	0.704069197
Adjusted R Square	0.700112903
Standard Error	0.846337437
Observations	380

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	637.3586408	127.472	177.961792	1.49247E-96
Residual	374	267.8913592	0.71629		
Total	379	905.25			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-151.5245407	12.30928517	-12.31	1.80976E-29	-175.728623	-127.320459	-175.7286227	-127.3204587
82TM	3.186188049	0.252105104	12.6383	9.83461E-31	2.69046693	3.681909169	2.69046693	3.681909169
82LX	-0.007031487	0.002142829	-3.2814	0.001130039	-0.01124499	-0.00281798	-0.011244991	-0.002817984
82RH	0.987331832	0.087375012	11.2999	1.13459E-25	0.81552397	1.159139694	0.81552397	1.159139694
82AU	7.908537076	0.90413141	8.74711	7.56205E-17	6.130718907	9.686355245	6.130718907	9.686355245
82PR	20.18855613	8.625357715	2.34061	0.019777389	3.228280785	37.14883147	3.228280785	37.14883147

Figure 23- Output of MRA for zone 5(01/08/2013)

Results of MRA on zone 5. There is a little variance between the R^2 and the adjusted R^2 values which means the output has little confidence for the predictions. The significance of ***f*** value is considerably low which gives better confidence for the predictions. The Equation 3 indicates the result of MRA on zone5 and the fig 23 displays the output residuals.

*Y=-151.524+(3.1861*Temp.-(0.007031*Lux)+(0.98733*RH)+(7.908*Audio)+(20.18*PIR)*

Equation 3-Regression equation from zone 5

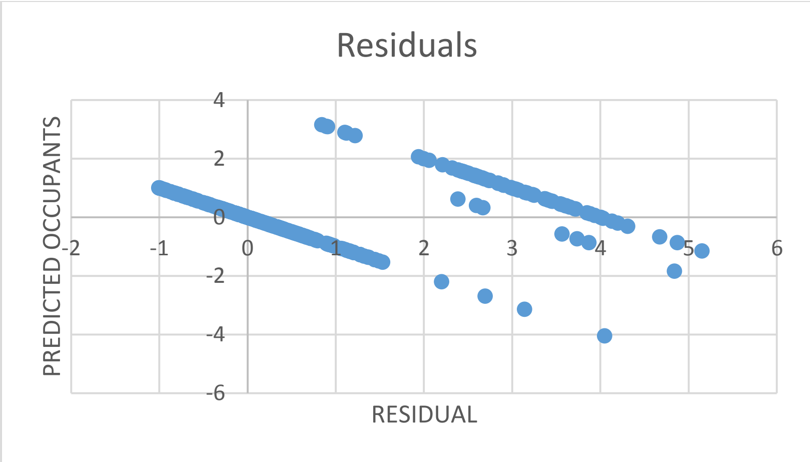


Figure 24- Output of residual for zone5

The figure 23 explains the output results of Z5 by the testing equation which was obtained as result of MRA on zone 5. It clearly highlights they have got significant relationship and that was being calculated. Providing an optimal adjusted R^2 value of 0.70 and a majority of p- values were less than 0.5 and it would make great contributions by using this equation.

Stage 4- Seasonal approach

The MRA is performed on zone 5 with all parameters included. The fig 24 indicates,

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.865495481
R Square	0.749082428
Adjusted R Squa	0.745046221
Standard Error	2.171272668
Observations	380

ANOVA

	df	*SS*	*MS*	*F*	*ignificance F*
Regression	6	5249.719475	874.95325	185.591	1.02E-108
Residual	373	1758.480525	4.714425		
Total	379	7008.2			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-555.1418828	49.92843957	-11.118751	5.4E-25	-653.3184	-456.9654	-653.3183853	-456.96538
TEMP.AVG	12.90611555	1.043493868	12.368176	1.1E-29	10.854247	14.957984	10.85424733	14.9579838
LUX. AVG	0.09942038	0.009846888	10.096629	2.4E-21	0.080058	0.1187828	0.080058008	0.11878275
RH.AVG	2.953216993	0.375345894	7.867988	3.9E-14	2.2151577	3.6912763	2.215157734	3.69127625
AUDIO.AVG	8.974229023	7.534165595	1.1911377	0.23436	-5.840535	23.788993	-5.840534528	23.7889926
PIR.AVG	-24.80880258	24.76262957	-1.0018646	0.31706	-73.50066	23.883053	-73.50065803	23.8830529
°C	6.142469522	0.314230531	19.547653	4.3E-59	5.5245841	6.7603549	5.52458411	6.76035493

Figure 25- Output of MRA for Seasonal approach

Results of MRA on seasonal approach. There is a little variance between the R^2 and the adjusted R^2 values which means the output has full confidence for the predictions. The significance of ***f*** value is considerably low which gives better confidence for the predictions. The Equation 4 indicates the result of MRA on seasonal approach and the fig 19 (Result section) displays the output residuals.

$$Y=-555.1418+(12.906*Temp.+(0.0994*Lux)+(2.95321*RH)+(8.9742*Audio)-(24.8088*PIR)+(6.1424*°C)$$

Equation 4- Regression equation from Seasonal approach

The figure 19 explains the output results of seasonal approach by the testing equation which was obtained as result of MRA on seasonal approach. It clearly highlights they have got significant relationship and that was being calculated. Providing an optimal adjusted R^2 value of 0.75 and a majority of p- values were less than 0.2 and it would make great contributions by using this equation.

5.5 Zone 5 vs. Seasonal Approach

Having seen the individual specification and outcome from both the cases, the most accurate regression output was generated from the stage 4 rom seasonal approach. On comparing their results fig 22 and 24, an adjusted R^2 value of 0.75(75%) from Seasonal Approach which highlights that the regression equation can be attributed to the input parameters of air temperature, relative humidity, lighting, audio, motion, and Ambient temperature(°C). A significance of ***f*** value was 1.02E-108 which is extremely low and gives confidence that the chosen input parameter are valid. The P values highlight that ambient temperature (°C), Lux and humidity are strongly related to occupancy numbers whilst temperature, audio and PIR were showing less correlation but they are still up to the level best. The t-Stat values measures the probability that a parameter is significant, the level of significance increases as the t-Stat value increase. Since the values of t-stat are comparatively high and that gives confidence towards this regression equation. The standard error of a regression is a measure of its variability. Which will provide accuracy based on the error value and the level of accuracy increases with increase in the standard error value. The Seasonal approach has obtained 2.17 as a Standard error which provide 95% of the accuracy approximately (Theoretically) .

Even though the zone 5 regression output (Fig 22) marks great result but it cannot be considered. The reason is, Zone 5 act as a meeting room where the occupancy level was zero for most of the time which makes this unit less interactive and unpredictable in nature.

5.6 Dominant Factors

The priority of the dominant factors that has better relationship between the occupants will be explained by the line fit plots of multiple parameters.

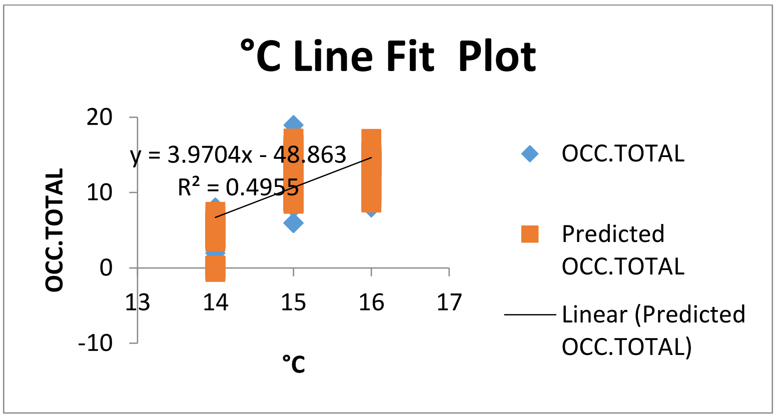


Figure 26- °C Line Fit Plot from stage 4.

The figures 25 &26 presents the accuracy of prediction over the ambient temperature and Lux. Output of this result helps to prioritise the dormant factor.

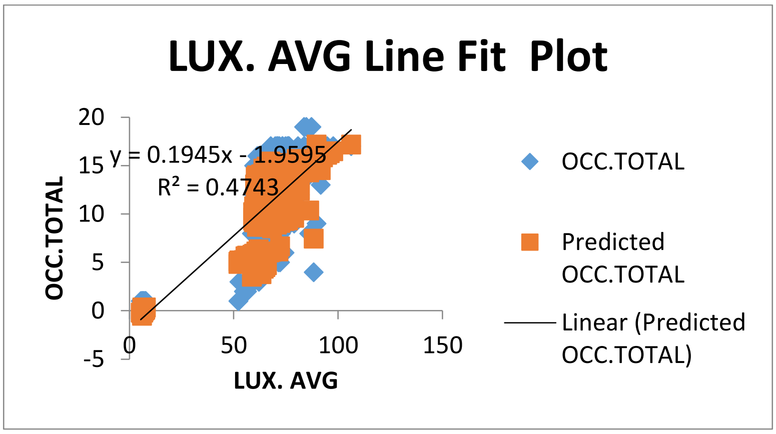


Figure 27- LUX. AVG Line Fit Plot from stage 4

Findings from this research made me to prioritise the dominant factor which would have great impact on the occupancy levels and they are, ambient temperature (°C), Lux, RH, Audio, Temp. And PIR (Refer Appendices).

The scatter plot (Fig 19) displays a random relationship between the regression and occupancy order. Which indicates the validity of the regression equation.

It can be concluded that considering the ambient conditions (weekend data) and previous study equation provided no improvement to the end results whilst treating the room as individual zones (Stage 1 and stage 2) provided a good results. Finally treating the whole plan as a single unit coupled with the seasonal approach brought the most significant result. The better residual outputs are obtained due to the greater amount of occupancy.

5.7 Summary

The discussion section briefly inferred the results from multiple research works that includes analyses like correlation, comparison, behavioural, and MRA for the multiple zones coupled with the seasonal approach. Finally the prime parts of this section is to present the most significant results obtained through MRA and that was presented as regression equation, statistical outputs, summarised tables. The most dominant factors that are identified from the results are discussed and justified with proper evidences. Those justifications, arguments on identifying the dominant factors and their evidences for the most accurate results have been discussed in this chapter.

6 Conclusion

This kind of research work was the first time to be carried out at the University of Strathclyde. Based on the research perspective it can be concluded that the methodology used in this project was satisfied and it can be integrated with "Regularised linear regression analysis" which could have added better accuracy in occupancy tracking and profile building.

Using seasonal approach with 6 parameters that is made up of Temp., RH, Lux, Audio, PIR and Ambient temperature, provided the most accurate regression output over the course of two working days. The results were obtained by treating the experimental area as a single unit, with all parameters included and the ambient temperature was taken into account which was manually collected from the updated weather report.

There was an unexpected and satisfied piece of result were obtained on analysing the individual zones. The zone 5 with all parameters included gave a significant result with the accuracy of 0.70 as R^2 value. Little to no meaningful results was produced by other individual zones and also by including the weekend data's.

In order to add credit to the regression output, the most dominant factors are identified based on the individual parameter line fit plots. The addition of occupancy shift within the zones gave a great piece of outcome and it actually increases the average accuracy of the regression.

The time step of 2 minutes helped to improve the accuracy of the results and it is anticipated to show more accuracy on including the ambient temperature with proper and conceived background ideas. It would also be of interest to consider applying the new predictive analysis methodology such as "Regularised Linear Regression analysis" and implementing them into the machine learning process coupled with over-fitting studies.

In order to further develop the accuracy of the methodology it is important to collect the details on the use of electronic/ electrical appliances. In addition to the third party data's such as windows and doors would contribute in the bringing the accuracy for the Predicting occupancy model/ Equation.

It is too early to compare this predictive methodology/ occupancy predicting model with the existing one. It is the most important duty of this research to answer about its uniqueness and how it can be applied to all sort of commercial buildings. Which can be done on enhancing this research into future work and on adding new technology to support the research.

7 Future work

This kind of research work was the first time to be carried out at the University of Strathclyde. As a result of this deriving the framework and making a proper plot for the research was quite challenging. Due to the time restrictions put on the project it was only possible to explore and adopt certain methodologies. It was clearly decided on its development stage that this project is hoped to get developed further by the students in the coming years.

Assumption were made in the most critical circumstances such as the loss of data's for the zone 4 during the weekend were the meaningful assumption are made by coupling the data's of other weekend.

Recommendations and areas of interest

It is important to think about the concepts of dividing the occupants before carrying out the analysis. The level of occupancy could be separated into active and passive sections based on the observational data, this would really help in calculating the distribution of occupants over the experimental site. This would also help for calculating behavioural analysis which is purely based on the interrelationships between the datasets

Inclusion of CO_2 Volatile Organic Compounds (VOC's)

In order to measure and control the indoor environment climate the inclusion of CO_2 and VOC's played a vital role in one of the previous study from the Institute of energy and sustainable development, De Montfort University. They have used CO_2, VOC's and PIR to track the occupancy level within the university. The experimental area was a kitchen and their results suggest that case temperature monitoring of electrical appliances is also a cost effective way to establish usage patterns, from which occupancy can be inferred (BAPI, n.d.).

This was really an inspiring investigation which could be integrated to our further research in future.

Admin support

It will be helpful to track the level occupancy by inheriting the admin support, which will acquire the possible information related to the occupancy level during the time of network usage which can be counted and gathered from the login details. Availability of this data, increases the level of accuracy in the observational one.

This type of ideas are only suitable for the non-domestic building which is purely dominated by the use of computers.

Third party data's

Considering the third party data's from effect doors and windows of the building would help to speculate the uncertainty in the indoor environment measurements. In case of occupancy tracking within the indoor environment the third party data's play a vital and might become one of the super influential factor for the occupancy tracking.

Additional predictive models

On including multi sensitive parameters into the research it would also be needed to have an additional predictive models that actually brings in better accuracy. The "Regularised Linear Regression Analysis" is one such predictive methodology which is used in statistics and particularly in the field of machine learning and inverse problems to prevent random errors and to improve the high level predictive performance.

Further the use of machine learning methodology helps in uplifting the process towards the controlling methodology. The plan of imposing this methodology into the research was delayed due to the time complexity.

Developing controlling strategies

It should be sequential in nature, the findings from the above predictive methodologies would help in bringing the new model for the occupancy prediction and that should be integrated with the derived control pattern which is based on the applications and the requirements. The most accurate predictive model would bring a better control algorithm.

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Appendices

Whole Plan Measurements for Weekday

TIME	TEMP.AVG	LUX. AVG	RH.AVG	AUDIO.AVG	PIR.AVG	OCC.TOTAL	Predictions	Resudials
09:55:58	22.414	61.282	63.26	0.031499167	0.68025667	11	8.4849493	6.32548
09:57:28	22.398	61.156	63.31	0.043453333	0.68332917	12	9.267942389	7.4641388
09:58:58	22.39	62.202	63.38	0.0536975	0.68064333	12	10.34293349	2.7458694
10:00:28	22.41	62.508	63.396	0.03854	0.66931	12	9.78078764	4.9249035
10:01:58	22.418	59.752	63.404	0.045763333	0.6826575	12	9.575952132	5.8760081
10:03:28	22.41	60.574	63.422	0.034574167	0.67763	11	9.089869146	3.6485999
10:04:58	22.416	59.35	63.45	0.0483225	0.6797275	11	9.883484766	1.2466063
10:06:28	22.434	62.078	63.456	0.03803	0.6758475	11	9.781034981	1.4858757
10:07:58	22.442	59.262	63.5	0.04708	0.6848525	11	9.900907751	1.2080038
10:09:28	22.446	62.944	63.52	0.045674167	0.68597583	11	10.39301219	0.3684342
10:10:58	22.456	61.596	63.534	0.05368	0.67913667	11	10.985734	0.0002035
10:12:28	22.45	59.81	63.556	0.0455025	0.67864917	11	10.22145546	0.6061316
10:13:58	22.446	63.694	63.626	0.0398225	0.6769425	11	10.63483444	0.1333459
10:15:28	22.444	61.148	63.646	0.038478333	0.68127417	9	10.10647546	1.2242879
10:16:58	22.438	59.344	63.668	0.0408325	0.67846667	11	10.10717266	0.7971407
10:18:29	22.45	61.216	63.694	0.067100833	0.67452083	14	12.37215774	2.6498704
10:19:59	22.456	60.636	63.744	0.06741	0.6780025	14	12.38262701	2.6158954
10:21:29	22.456	59.764	63.782	0.0385625	0.67806083	15	10.41711606	21.002825
10:22:59	22.464	61.006	63.834	0.058765	0.67745333	15	12.15262375	8.1075515
10:24:29	22.456	62.74	63.866	0.0371	0.6758	16	11.04954376	24.507017
10:25:59	22.466	65.966	63.87	0.0513025	0.67960833	16	12.43612081	12.701235
10:27:29	22.468	60.53	63.908	0.0495875	0.67936	15	11.63888726	11.297079
10:28:59	22.494	61.786	63.926	0.048525833	0.67290833	16	12.07136334	15.434186
10:30:29	22.492	62.048	63.918	0.03586	0.67811833	16	11.09505839	24.058452

Seasonal Approach measurements

TIME	TEMP.AVG	LUX. AVG	RH.AVG	AUDIO.AVG	PIR.AVG	°C	OCC.TOTAL	Predicted
09:55:58	22.414	61.282	63.26	0.03149917	0.680257	16	11	63.56625003
09:57:28	22.398	61.156	63.31	0.04345333	0.683329	16	12	63.41319727
09:58:58	22.39	62.202	63.38	0.0536975	0.680643	16	12	64.71517118
10:00:28	22.41	62.508	63.396	0.03854	0.66931	16	12	65.46990954
10:01:58	22.418	59.752	63.404	0.04576333	0.682658	16	12	62.59045692
10:03:28	22.41	60.574	63.422	0.03457417	0.67763	16	11	63.38191054
10:04:58	22.416	59.35	63.45	0.0483225	0.679728	16	11	62.39647978
10:06:28	22.434	62.078	63.456	0.03803	0.675848	16	11	65.36257757
10:07:58	22.442	59.262	63.5	0.04708	0.684853	16	11	62.65391323
10:09:28	22.446	62.944	63.52	0.04567417	0.685976	16	11	66.38476125
10:10:58	22.456	61.596	63.534	0.05368	0.679137	16	11	65.45650292
10:12:28	22.45	59.81	63.556	0.0455025	0.678649	16	11	63.60710329
10:13:58	22.446	63.694	63.626	0.0398225	0.676943	16	11	67.61504259
10:15:28	22.444	61.148	63.646	0.03847833	0.681274	16	9	64.99753491
10:16:58	22.438	59.344	63.668	0.0408325	0.678467	16	11	63.28230938
10:18:29	22.45	61.216	63.694	0.06710083	0.674521	16	14	65.70873685
10:19:59	22.456	60.636	63.744	0.06741	0.678003	16	14	65.273596
10:21:29	22.456	59.764	63.782	0.0385625	0.678061	16	15	64.25854479
10:22:59	22.464	61.006	63.834	0.058765	0.677453	16	15	65.94652901
10:24:29	22.456	62.74	63.866	0.0371	0.6758	16	16	67.50831658
10:25:59	22.466	65.966	63.87	0.0513025	0.679608	16	16	70.88945548
10:27:29	22.468	60.53	63.908	0.0495875	0.67936	16	15	65.61378817
10:28:59	22.494	61.786	63.926	0.04852583	0.672908	16	16	67.40175007
10:30:29	22.492	62.048	63.918	0.03586	0.678118	16	16	67.3698731

Zone 5 measurements

TIME	Z5.OCC	82TM	82LX	82RH	82AU	82PR	prediction	Resudial
09:55:58	0	20.63	12.91	72.18	0.0101	0.67047	-0.821877	0.67548
09:57:28	0	20.61	15.28	72.14	0.01461	0.67667	-0.747543	0.55882
09:58:58	0	20.61	14.12	72.2	0.0103	0.67281	-0.808491	0.65366
10:00:28	0	20.61	14.69	72.25	0.01	0.67117	-0.7906	0.62505
10:01:58	0	20.61	15.54	72.29	0.0103	0.68258	-0.51244	0.2626
10:03:28	0	20.61	12.48	72.25	0.0102	0.67036	-0.820873	0.67383
10:04:58	0	20.61	13.5	72.29	0.0104	0.67159	-0.747813	0.55922
10:06:28	0	20.63	14.61	72.2	0.0103	0.67403	-0.716643	0.51358
10:07:58	0	20.64	12.34	72.2	0.00979	0.66824	-0.821768	0.6753
10:09:28	0	20.64	20.7	72.18	0.012	0.67454	-0.638008	0.40705
10:10:58	0	20.64	18.39	72.22	0.01	0.66955	-0.731294	0.53479
10:12:28	0	20.66	14.28	72.25	0.014	0.6721	-0.583747	0.34076
10:13:58	0	20.66	13.89	72.26	0.0107	0.67027	-0.639759	0.40929
10:15:28	0	20.66	12.48	72.22	0.0103	0.67403	-0.616317	0.37985
10:16:58	0	20.66	13.58	72.25	0.011	0.67545	-0.544711	0.29671
10:18:29	0	20.67	13.73	72.26	0.0112	0.6665	-0.68106	0.46384
10:19:59	0	20.67	17	72.29	0.0097	0.66865	-0.597077	0.3565
10:21:29	0	20.67	15.63	72.29	0.0104	0.67017	-0.570469	0.32543
10:22:59	0	20.67	17.19	72.29	0.0101	0.66936	-0.578161	0.33427
10:24:29	0	20.67	19.68	72.33	0.0101	0.67362	-0.435193	0.18939
10:25:59	0	20.7	20.24	72.31	0.0098	0.67648	-0.299949	0.08997
10:27:29	0	20.68	20.47	72.29	0.01	0.67647	-0.380525	0.1448
10:28:59	0	20.7	19.46	72.31	0.01172	0.67668	-0.286339	0.08199

Fit plots for seasonal approach